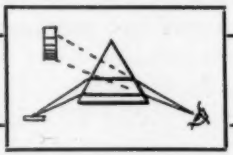
JOURNAL
of the
OPTICAL SOCIETY
OF AMERICA

VOLUME 22
No. 3



MARCH
1932

BROCK PROCESS OF AERIAL MAPPING*

By Edward H. Cahill†

[Philadelphia, Pa. Received December 30, 1931]

Military needs accelerated the development of photographic surveying. Photography was invented in 1839, and as early as 1846 military officers were using photographs from terrestrial stations as an aid to mapping. The first scientific application of the principles of photography to surveying was made in 1854 by Colonel A. Laussedat of the French Army. Four years later, he made the first application of the principles of aerial photography. In 1859 Nadar attempted to use aerial photography in planning a military engagement. It was at Richmond, Virginia, in 1862 that the first successful military use of aerial photography was made. The aerial attempts of Laussedat and Nadar failed because of the cumbersome wet plate apparatus, and not due to ignorance of aeronautics; as considerable knowledge in this art had been acquired since the first balloon ascension in 1776, in France.

During the ten years prior to the World War, military officers of several European countries were studying the problems of aerial mapping. The most difficult problem was to determine the unknown angle at

* Presented before The Optical Society of America on October 29, 1931 at Rochester, N. Y.

† Chief Engineer Precision Engineering Co., Philadelphia, Pa.

which the axis of the camera lens was inclined at the instant of exposure. The solution of the angles of oblique pictures is necessary in drawing accurate contours. In Vienna, in 1906, Captain Theodore Scheimpflug, of the Austrian Army, disclosed his method of transforming oblique pictures of known inclination. Later he made other disclosures of methods by which he proposed to determine the unknown tilt angles of oblique aerial pictures and construct topographic maps from them. Others in Europe, especially those familiar with terrestrial photomapping, became interested in the aerial problems, but it is substantially true to say that none presented a solution not already disclosed by Scheimpflug.

Scheimpflug's aerial camera had one central lens surrounded by seven other lenses that were equally spaced and inclined so that their axes intersected at one point in the axis of the central lens. All of the lenses had independent focal planes. By means of his perspectograph the oblique pictures were transformed to the plane of the central picture. When combined, the eight views represented a single picture taken with a lens of 140 degrees visual angle.

Contrary to general opinion, interest in the art of aerial mapping was not lacking in the United States. In a paper presented at a meeting of the Photogeometric Society at Vienna, April 15, 1909, Captain Scheimpflug stated:

> "A very remarkable solution of the problem, which is probably little known in this country, originated from an American, Mr. Cornel Berrien Adams, and is found in an American patent of 1893. The solution is remarkable for that time, and proves the great practical mind of the Americans, . . . From two such pictures he then finds the difference in height of the ground in the manner generally known today, but which much later authors repeatedly consider as a new achievement. As we see it, the man was theoretically rather far advanced, though I do not know anything of the practical utilization of his patent."

Excepting the theory of transforming oblique pictures, it is probable that Adams anticipated the principles disclosed in Europe up to the time of Scheimpflug's death in 1911.

Notwithstanding the early work of the European armies, none of them had a suitable camera at the beginning of the war in 1914. Not until well into 1915 were cameras constructed that gave results approaching the desires of the Armies. The Germans abandoned Scheimpflug's multi-lens camera, and for the first time, at the battle of the Somme, 1917, used a series picture camera having a single lens. It is understood that the camera was designed in 1915 by Messter.

The Brock mapping process began with the World War. The process, as it exists today, and all equipment used in its performance, were developed, designed and constructed by the Arthur Brock Tool and

Manufacturing Works, Philadelphia, Pa —now the Precision Engineering Company.

Design of the first camera was started in October, 1914, and its construction completed early in 1915. As roll films of adequate size were not available, provisions were made for use of both ferro types and cut films. The camera was free to pendulate in its mount, and contained a gyroscope to hold the lens axis in the vertical. The camera and gyroscope were driven by separate electric motors.

Its first practical demonstration was made at Fort Sill in the summer of 1915. At the time few aeroplanes existed and their performances were more remarkable than consistent. About six weeks were spent in obtain-

FIG. 1

ing a suitable plane, in mounting the camera, and in making the actual demonstration. From the pictures obtained the relative positions of new buildings were plotted graphically and checked with existing maps of the fort. Several picture maps or mosaics were also make; one of which was published in 1916, in FIELD ARTILLERY JOURNAL (Fig. 1). The demonstration proved that the gyroscope would not produce the desired results, and that an aerial camera should have greater picture capacity.

In the meantime, roll films of adequate size were promised, and a new camera was constructed. It was driven by a spring motor, and had capacity for 100 four-inch by five-inch pictures. This camera was used

at the Mexican border in 1916. Subsequently, the design was improved, and cameras produced in quantity in 1917; (Fig. 2). During the same year a fully automatic camera having magazines for 24 plates, 4 inches by 5 inches, was constructed in quantity.

Throughout the war, and well into 1921, the Precision Engineering Company made many experiments relating to methods of making topo-

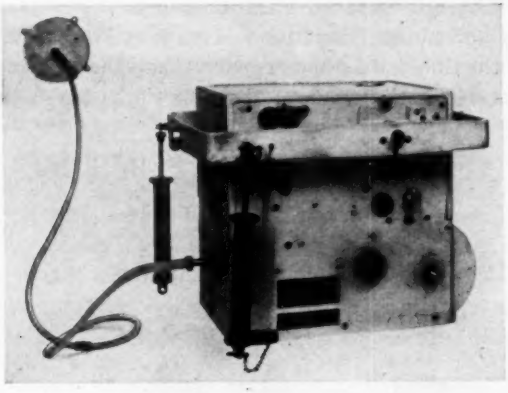


FIG. 2

graphic maps from aerial photographs. The knowledge gained from these experiments led to the following conclusions:

1. In making topographic maps from aerial pictures, some operations can be performed without the use of a machine, and those operations performed on machines do not require the same amount of time. Therefore, a single machine performing all operations would not be economically successful, as its output would be limited by the operation requiring the most time.

2. Because of liability of relatively large errors introduced by angular displacement of optics, due to lost motion and deflection of supporting members, non-movable optical systems should be used where possible.

3. That until film free of non-uniform shrinkage or expansion is available, aerial pictures should be made on glass plates, for accurate determination of contours.

These ideas were carried out in a new set of machines, and while the decision was subject to change as required by future development, nothing at this date has warranted deviation from these conclusions. Improvements, however, can be made in the present equipment, which will greatly facilitate performance. It is well known to the engineer that the best machine is never built, as the latest one can always be improved.

It is desired to emphasize here that it is due to accuracy requirements for determining contours that plates were adopted. The disadvantages of plates are weight and bulk. Breakage is a negligible factor, as no work has been affected due to loss of a plate. But plates are more accurate, and are more easily handled and developed. However, for military purposes and for mosaics, film cameras will perhaps remain the most suitable; though it is quite probable that a plate camera may be a valuable military auxiliary.

During war an army cannot wait for ideal weather conditions, therefore a military camera should have a lens of large aperture. A large aperture limits the visual angle of the lens, resulting in less ground area per picture. Large numbers of pictures may be taken, and unusual skill is not required to piece them into a picture map commonly called a mosaic. Such a map is not accurate, but it contains a vast wealth of information of sufficient accuracy to serve the purpose of the army. The effect of lens distortion need not be considered, as it is only a fraction of the image displacement caused by ground relief. As distortion is not a considerable factor, plate glass may be used to support the film in the focal plane of a military camera. If a lens were perfect, distortion would be introduced by the glass support. However, it is also true that this defect in some lenses may be corrected by the glass; as in the method described by Gardner and Bennett, "The Compensation of Distortion in Objectives for Airplane Photography," J.O.S.A. and R.S.I. *14*, 245–250; 1927.

For making topographic maps, it would also be desirable to take pictures in any kind of weather, but this is a peace time occupation in which the haste of war does not exist and provisions may be made for other important requirements. In making topographic maps, it is necessary to spend a relatively large amount of time on each picture after it is taken. As the cost of mapping is affected by the time spent on a picture, it is desirable that each include the greatest ground area possible, which will reduce the number. Pictures embracing large areas can be made with a wide-angle lens of short focus. With one camera using such a lens, sufficient photographs can be taken during selected weather conditions to keep a relatively large number of operators employed for a long period in the actual construction of topographic maps. Under favorable light conditions smaller apertures can be used, which lend to the design of a wide-angle lens. For topographic maps the lens must be practically free from distortion, otherwise the parallax values in a stereoscopic pair of pictures will not represent the true ground relief.

THE BROCK PROCESS[1]

In addition to the aerial photography, the general operations of the Brock Process are (a) plotting the horizontal position of pictures, (b) horizontalizing pictures, (c) contouring, (d) scale equalizing and (e) assembling the picture information in the final map. The field work for horizontal control and for use in horizontalizing pictures is included in operations (a) and (b) respectively.

The camera, (Fig. 3) is provided with magazines that contain 48 plates, 6.5 inches by 8.5 inches. It is mounted in a gimbal, but free oscillation is dampened by hydraulic dash pots. During operation the magazine travels vertically, which causes no deviation of the optical

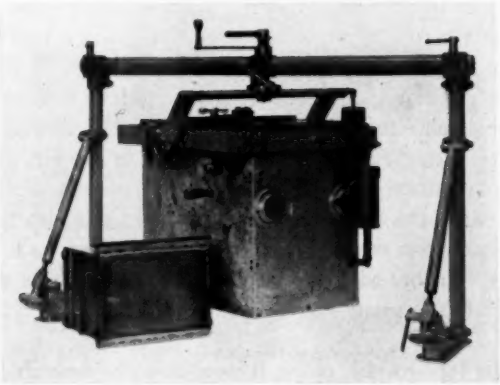


FIG. 3

axis. Means are provided to quickly compensate for the unequal weights of the loaded magazines. The camera is operated by hand. By turning a hand-wheel, a plate is fed into the focal plane and the lens shutter charged. The hand-wheel mechanism then automatically locks and is released by the shutter mechanism only after the plate is exposed. The exposed plate is returned to the magazine, the magazine elevated and a new plate brought into the focal plane. The operation is continued until all plates are exposed. The magazine of exposed plates is then removed from the camera and replaced by another one containing unexposed plates. It is possible to complete a change of magazines and be ready for new exposures in ten seconds.

[1] The Brock process is operated by Brock and Weymouth, Inc., Philadelphia, Pa.

The pictures are enlarged about two diameters on glass plates, to facilitate accurate plotting of horizontal positions, and accurate horizontalizing of plates. Also, contours of close proximity and other details may be more easily drawn on the increased area.

PLOTTING HORIZONTAL POSITIONS OF PICTURES

Pairs of overlapping pictures are placed in the stereoscope, (Fig. 4), and each is covered with a transparent sheet of paper. Conjugate image points on each picture are visible through the paper, and by means of a marking tool very small perforations are made in the paper and in the emulsion of the plate. Some of the perforated points on each picture

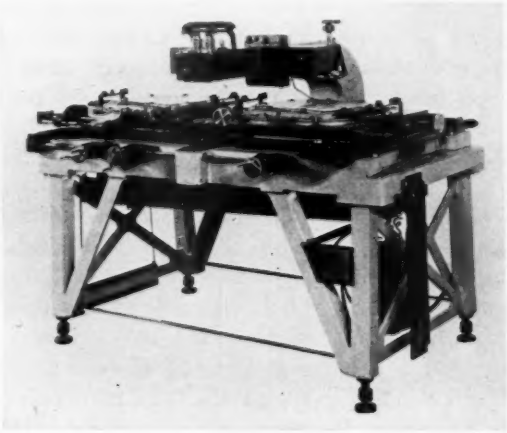


FIG. 4

represent ground points of which elevations only are determined in the field, for use in horizontalizing the pictures. Since horizontal control is necessary in plotting, on some of the pairs are included two points that are extremities of a line whose distance and azimuth are determined in the field. Using the picture center as the origin, radial lines are drawn through all the tiny perforations in the transparent sheets.

By the radial line method, the picture control is plotted in relation to the lines of known distances and geographical positions, which have been laid to scale on coordinate sheets. Such lines may be from five to twenty miles apart, depending on scale, and on the accuracy desired. The positions of all the points of known elevations also appear in the

plot, and from them the elevation of the lens point of each picture is determined. The radial line method of plotting is well known and needs no explanation.

Because of the small tilt in the pictures it is seldom necessary to horizontalize a picture for plotting. In one survey requiring about 300 pictures, only 29 were tilted greater than one degree. Of the 29 only 5 were tilted more than 1°-30′, one of which was tilted 2°-19′. The average tilt, determined by adding the tilt of all pictures and dividing by the number of pictures, was 34.9 minutes. Such conditions are typical, and the small tilt is no doubt due to the camera suspension.

In plotting the horizontal control it is necessary to horizontalize a picture only to determine the vertical or nadir point of the picture, which is used as the origin of the plotting template. If the nadir position were known, horizontalizing would be unnecessary because the direction of images relative to this point never changes. For drawing contours, however, horizontalizing is necessary because images are displaced in lines radiating from the nadir.

CONTOURING

After the pictures are horizontalized, as described later, they are placed in the stereoscope, where all contours and other detail are drawn on a transparent sheet superimposed on one of the pictures. The pictures are aligned in respect to their vertical points and then fastened in this alignment. The parallax slide provides for movement of only one picture parallel to this alignment. When the pictures are set at proper separations, corresponding to the parallax of a particular contour, the parallax slide is fastened. By means of the coordinate hand wheels all parts of the pictures are brought into the view of the optics, but there is no relative movement of the two pictures and there is no movement of optics.

The two reticules of the optical system each consist of two very fine lines intersecting at right angles. The lines are respectively parallel to the motion of the coordinate slides. The reticule line perpendicular to the line joining the picture verticals is the parallax line. The other reticule line is parallel to the picture alignment and is used for measuring ordinates and for aligning the pictures. When viewed through the eyepieces, the two reticules blend into one pair of intersecting lines and give the sensation of establishing a horizontal plane. Contours are not "sketched" in reference to this plane, but are drawn only where the parallax line appears to lie on the ground. Over ground below the par-

ticular elevation of a parallax setting, the cross-lines seem to hang in space, and when on higher ground the parallax line appears to split. The operator uses that part of the parallax line near the intersection with the other line of the reticule. Where this point in the line appears to touch the ground, the contour is drawn on the paper, and the operation is continued until the whole meandering contour and all adjacent detail are drawn. The parallax slide is then moved the proper parallax for the adjacent contour, and the operation is continued. The operator does no computing; all parallax data are furnished him with each pair of pictures.

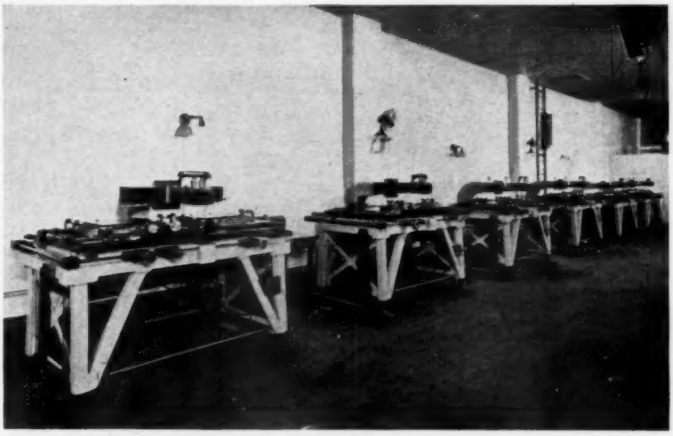


FIG. 5 *Battery of stereoscopes.*

The field viewed through the oculars is the area of a two and one-half inch circle, so that a large area of the picture is always visible. This feature greatly aids in developing the shape of the ground; contours already drawn can be observed as a new one is added, thus avoiding such errors as crossed contours, especially on abrupt slopes.

SCALE EQUALIZING

The stereoscope sheet, still a conic projection, is placed in an automatic focusing projector, (Fig. 6.) Its image appears on another transparent paper over the image plane of the machine. Because of the presence of the contours, it is possible to determine and to furnish the operator with data for the reductions and enlargements necessary to bring all the

detail to a common scale. By successive operations an orthographic projection is drawn on the new sheet, which includes necessary control to permit of assembling in the final map.

The map, Fig. 7, was made by the method described, and is one section of nine covering a recent survey of the Colorado River near the Hoover Dam site. The scale is 1/4800, with five-foot contour intervals. The relief in ground embraced by a pair of stereoscopic pictures is in some cases as much as 1500 feet. The pictures were taken approximately 6,000 feet above the river, and this low altitude together with the extremely high temperatures produced very bumpy and difficult flying conditions. In spite of these adverse conditions, the average tilt in 150 pictures was approximately fifty minutes. Because of this ground relief

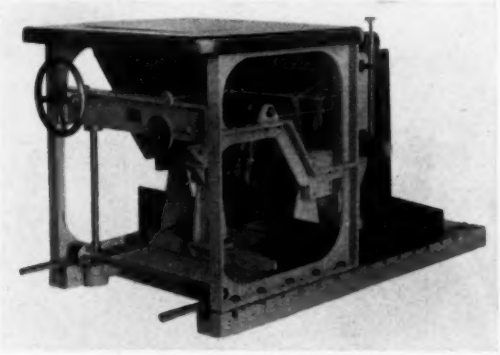


FIG. 6

and excessive tilt, it was necessary to horizontalize 9 pictures to locate their vertical, nadir, points for use as the origins in plotting the horizontal control. It is well known why such relief affects the radial line plotting if the optical centers of tilted pictures are used as the origins.

CORRECTION

As no adequate solution of the tilt problem by means in the camera is known, reference to the ground is necessary. From time to time mathematical relations existing in a single picture or a stereoscopic pair of pictures are discovered, which present a method of solution. The fundamental difference between the European and the Brock methods of solution is that knowledge of only the elevations of ground points is necessary in the Brock method, whereas knowledge of both vertical and horizontal positions of points is required by the European methods.

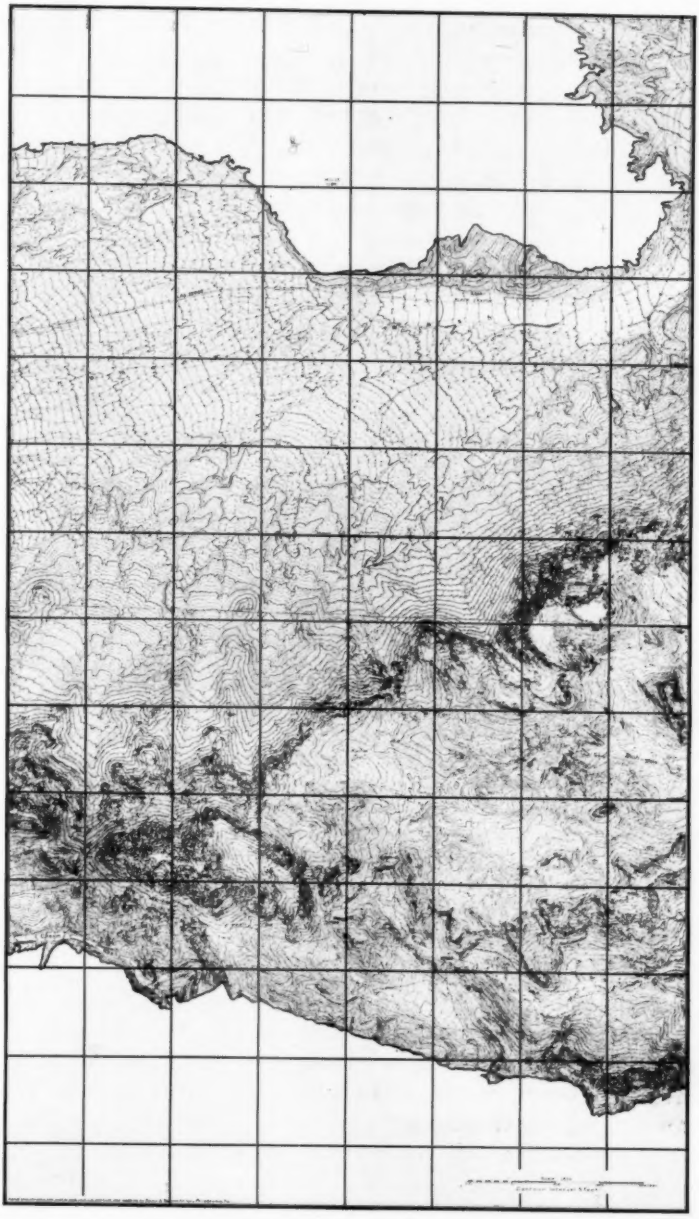


FIG. 7

In the Brock Process use is made of the relation that in a stereoscopic pair of vertical pictures the coordinates of related images will be in agreement. Fig. 8 represents two pictures in the same horizontal plane. The traces of the vertical lens axes are v_1 in picture No. 1 and v_2 in picture No. 2 and are also the images of the foot points V_1 and V_2 of the respective verticals. The conjugate images of these foot points also appear on the pictures. Using the traces as points of origin, abscissas of points are measured parallel to the lines joining v_1 and v_2; ordinates are measured perpendicularly to these lines. As the pictures are in the same horizontal plane, the ordinates of images a_1, b_1, and d_1, of one picture are equal respectively to the ordinates of their conjugate points a_2, b_2, and d_2 of the other picture.

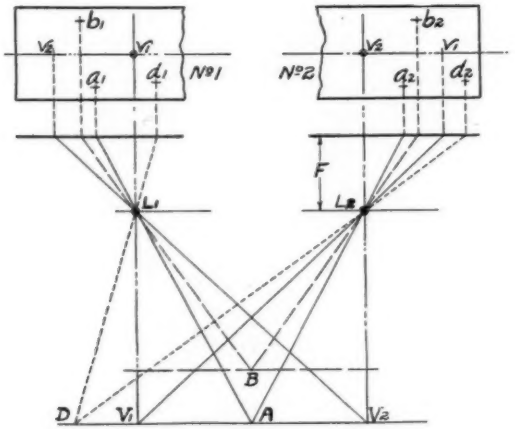


FIG. 8

The distances v_1 v_2 and v_2 v_1 on the pictures are equal as they are bases of equal right triangles, and they represent the picture base, in respect to the ground plane A, of the distance between the two verticals. The ground point A will be imaged at a_1 and a_2 respectively, and the sum of their abscissas, v_1 a_1 and v_2 a_2, will equal the picture base v_1 v_2. Therefore, on a pair of stereoscopic pictures in the same horizontal plane, the sum of the abscissas of conjugate image points will be equal to the picture base in respect to the horizontal plane of the object point. This is true regardless of the position of the point in the plane. Thus for point D, the abscissa v_1 d_1 on one picture is minus, as the image d_1 appears between the verticals, and the algebraic sum of v_1 d_1 and v_2 d_2 will equal v_1 v_2. The sum of the abscissas v_1 b_1 and v_2 b_2 will be the picture base

in respect to the plane of B. The difference between the picture bases is the parallax. There is no parallax in respect to points in the same horizontal plane.

The ground points may be considered to lie in different planes and in the vertical axis of one picture, Fig. 9. The abscissas of the points will then be zero in picture No. 1 and the picture bases will be the abscissas in picture No. 2. In respect to the plane of A, the parallaxes of planes B and D will be p and p_1 respectively.

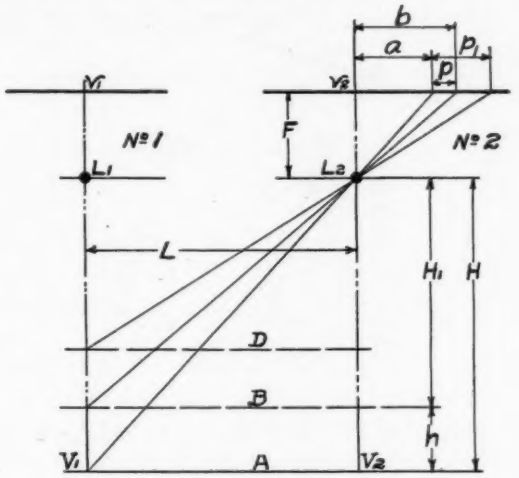


FIG. 9

If L be the distance between the two verticals, a the picture base of plane A, and b that of plane B, then from the relation of the triangles in the Fig. 9 we have

$$H = \frac{FL}{a} \tag{1}$$

and

$$H_1 = \frac{FL}{a + p}. \tag{2}$$

Dividing (1) by (2) and letting $H_1 = H - h$, the parallax may be found from the relation

$$p = \frac{ah}{H - h}. \tag{3}$$

From which h, the difference in elevation, will be

$$h = \frac{pH}{a + p}. \tag{4}$$

From equations 3 and 4, tables have been constructed from which any parallax values may be interpolated.

Due to tilt the parallaxes and ordinates in any original pair of aerial pictures do not agree and the purpose in correction is to eliminate by

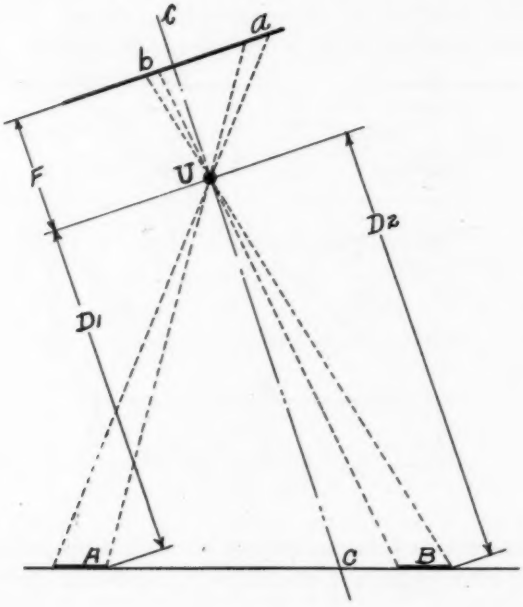


FIG. 10

projection the excess quantities found relative to those that would exist in a horizontal pair having altitude and picture base determined from the picture plot. The inclination of the lens has the effect of changing the distance between the lens and every point on the ground, causing a non-uniform change in size of the images on the picture, also in their relative positions. This is illustrated in Fig. 10 which represents a camera tilted about an axis that is perpendicular to the plane of the paper and passes through the lens U. The axis of the lens inclines to the horizontal ground plane containing objects A and B of equal size. The

first and second nodal points are considered to be at one point and to lie in the plane passing through the lens and perpendicular to its axis. Object distances from the lens plane are measured parallel to the lens axis, therefore, as indicated by D_1 and D_2, the object A is nearer than B to the lens plane. Because of this the image a will be larger than image b.

Theoretically, it may be assumed that an oblique picture can be made with a lens of variable focus and having a vertical axis; the images being made on a large number of horizontal planes at their intersections with an oblique plane. This is illustrated in Fig. 11 from which the object points below the lens U are omitted.

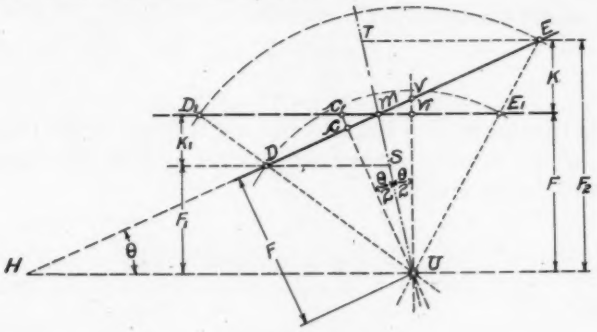


FIG. 11

In the figure the lens axis cU is tilted at the angle θ with the vertical vU and is perpendicular to the inclined picture plane DE that is at the focal distance F from the lens U. The point c is the trace of the optical axis in the focal plane and also represents the image of the ground point in this axis. The point v is the trace of the vertical vU and also the image of the ground point in the vertical. At D and E are images of any object points on the ground. The broken line D_1E_1 represents the ideal horizontal focal plane of a vertical lens and contains points D_1, c_1, v_1 and E_1, which are the positions the images would occupy if the lens axis were vertical. The intersection of the oblique and horizontal picture planes at m is the only line in which images are not affected by the camera tilt. This line is perpendicular to the plane of the paper and is always parallel to the tilt axis and to the horizon line H that is the intersection of the oblique picture plane with the horizontal plane through the lens U.

If the axis of the lens were vertical and its focus variable, the images D, m, and E could be made at focii F_1, F and F_2, respectively, in the

horizontal focal planes DS, D_1E_1 and TE at their respective intersections with the oblique picture plane.

Due to tilt, all images at the left of m are reduced in size and those at the right have been enlarged. It should be understood that the points D, D_1, E, E_1, etc., also represent lines that are perpendicular to the plane of the paper, and that sizes of all images in these lines are affected.

The amounts that the sizes and positions of images on a horizontal picture plane differ from those on an oblique picture taken from the same lens point can be determined from mathematical relations developed from Fig. 11.

In the similar triangles UTE and UmE_1

$$\frac{mE_1}{TE} = \frac{F}{F_2}.$$

But the triangle mTE is isoceles, and mE is equal to TE. Designate mE and mE_1 by L and l respectively, and let n be the size factor of l to L, we shall have the relation

$$n = \frac{l}{L} = \frac{F}{F_2} = \frac{F}{F + K} = \frac{F}{F + L \sin \theta}. \tag{5}$$

From which

$$l = L \frac{F}{F + L \sin \theta}. \tag{6}$$

In like manner, from triangles UD_1m and UDS may be found the relation

$$L_1 = l_1 \frac{F}{F - l_1 \sin \theta} \tag{7}$$

where L_1 and l_1 are D_1m and Dm respectively.

By construction, as indicated by the arcs D_1E and DE_1, L_1 and l_1 are equal respectively to L and l so that if l is assumed or known, L may be found from the relation

$$L = l \frac{F}{F - l \sin \theta}. \tag{8}$$

Because of the relation of the variables L and l in equations 6 and 8 respectively, there will be a different enlargement for each position occupied by E in the oblique plane. Therefore, a particular value of n relates to images only in the line containing E and perpendicular to the plane of the figure.

If L and l are known, from equation 6 will be found

$$\sin\theta = \frac{F(L-l)}{Ll} \tag{9}$$

and if we let $e = L - l$ equation 9 will reduce to

$$\sin\theta = \frac{Fe}{L(L-e)}. \tag{10}$$

From which may be obtained

$$e = \frac{L^2}{L + \dfrac{F}{\sin\theta}} \tag{11}$$

also

$$e = \frac{l^2}{\dfrac{F}{\sin\theta} - l}. \tag{12}$$

Moreover, if the displacement e is known but L and l are unknown, by substituting $(L-e)$ for l in equation (6) it will reduce to

$$L = \left(e\frac{F}{\sin\theta} + \frac{e^2}{4}\right)^{1/2} + \frac{e}{2}. \tag{13}$$

Use of these relations may be made by students in their studies of the difference between horizontal and oblique picture planes. For a fixed focus F and tilt angle θ the relation $F/\sin\theta$ will be constant, and the trigonometric tables need be consulted only to find the sin θ. The image forming rays and their included angles do not appear in these equations, which greatly reduces the amount of computing.

In the Brock Process use of some of these equations has been made to construct charts that are used in conjunction with the correcting projectors. As tilt angles in aerial pictures are relatively small, the trigonometric functions vary almost directly, and very few charts are necessary. The charts very quickly indicate the angles at which the focal planes of the projector must be tilted in order that the projected image of the aerial picture will be a horizontal equivalent.

PROJECTING ON TILTED PLANES

The foregoing discussion indicates correction by projecting with the true scale line m on the optical axis and in the tilt axes of a projector, in

which case the new picture will be of the scale of the ideal horizontal plane, Fig. 11. The advantages of using a projector conforming to these relations may be understood from study of Fig. 12. Mathematical discussions of this problem have been presented by Scheimpflug, and M. Clerc of the French Army, but in this paper the development is different, and may perhaps remove apparent misunderstanding relating to use of the lens, and to the circle that is the locus of lens positions or points of conic projections.

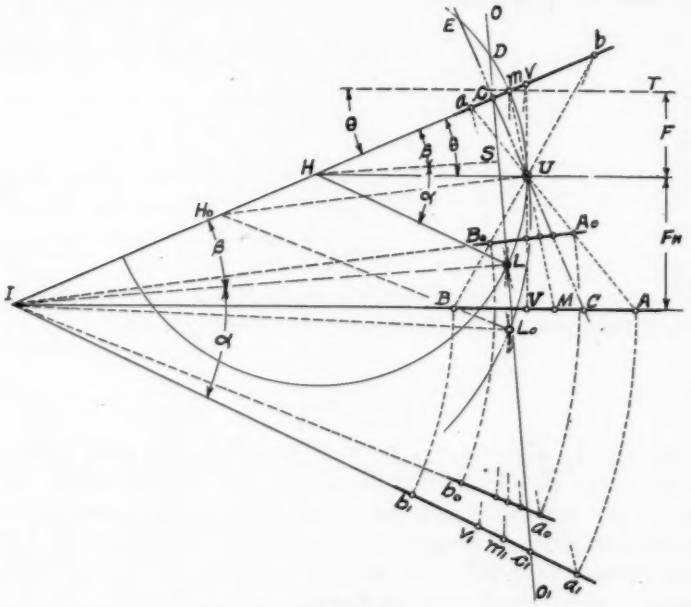


FIG. 12

In Fig. 12 the line ab is a picture taken with the lens axis cU inclined the angle θ to the vertical vU. The plane mT is the ideal horizontal plane at the focal distance F above the lens U.

For the present, disregard lenses and consider the point U as a pinhole or the point of projection. Pass a horizontal plane at any distance F_N below U, and it will intersect the prolonged oblique picture plane at I. Rays from the points a, c, m, etc., will pass through the point U to B, V, M, etc., which will be a horizontal picture.

This desired picture may be obtained on another plane by revolving

it about I to any plane Ib_1. Rays connecting the related points b_1 and b, v_1 and v, etc., will intersect at one point L. If the plane Ib_1 be revolved through any other angle, the connecting rays will intersect in a point other than L. A plane containing U and parallel to IB will intersect the oblique plane at H, and a circle with its center at H and of radius HU will pass through L and any other point of projection. The circle DUL is the locus of all points of projection in respect only to planes parallel to IB. The plane HU of the projection point U has been revolved to HL, through angle of arc UL, which is equal to the angle of arc Aa_1. It is necessary, therefore, to revolve the plane of the projection point through the same angle as the plane that receives the image.

The picture ab may be projected on any inclined plane B_0A_0 that intersects the oblique picture plane, in this case, at I. If this plane be revolved to plane Ib_0, the rays connecting the related points a, c, m and a_0, c_0, m_0, will intersect in a point L_0, which is not in the circle DUL. The perpendicular from U to IB_0 is the axis of the projection B_0A_0, and the plane of U is now H_0U, and is perpendicular to this axis and parallel to IB_0. With H_0 as a center and H_0U as a radius, draw the arc UL_0, which is the locus of all points of projection in respect to planes parallel to the oblique picture B_0A_0 only. The angle measured by arc UL_0 is equal to the angle measured by arc A_0a_0.

Considering only the horizontal picture, let L be the lens of a projector, with its axis OO_1 passing through the center c of the oblique picture. The chord LD will then represent twice the equivalent focus of the lens L, for the reason that its bisector HS is the only perpendicular that contains the horizon line H. Then HS will be the front focal plane of the lens, and the horizon line H will be projected on an infinitely distant plane. Furthermore, the plane of rays HL is parallel to Ia_1 and no image of H will be received.

As SD is equal to the focus f of the projector lens, point c is less than f from the focal plane HS. So that cS is f/n and the picture b_1a_1 is an enlargement of ba. With the particular lens the only horizontal picture that can be produced with the point c on the optical axis is the enlarged picture b_1a_1. Furthermore, with the same lens f there will be a different enlargement for a different tilt θ. In respect to the size of image c the enlargement ratio of the picture b_1a_1 is n, but in respect to the ideal plane mT the enlargement ratio will be $n \cos \theta$.

From triangles HUc and HLS will be found the relation

$$\sin \alpha = \frac{f}{F} \sin \theta. \qquad (14)$$

Where f and F are respectively the focii of the projector and camera lenses. So that there will also be a different tilt in the plane Ib_1 in respect to the optical axis, according to the focii of the lenses.

Since

$$n = \frac{Lc_1}{Lc}$$

from right triangles ILc and ILc_1 will be found the relation

$$n = \frac{\tan \alpha}{\tan \beta}. \tag{15}$$

In the figure the angle α will be constant for a particular tilt θ, but for projecting with other points than c on the optical axis, there will be a different angle β, and as expressed in equation 15 there will also be a different enlargement.

This will be better understood if a transparent sheet be placed over the figure and a tracing made thereon of the lens axis OO_1, the circle DL and the lines HS and HL. If the tracing be revolved clockwise about the point H, the chord LD will intersect the picture plane in different points as it passes to the right of c. When D reaches m the enlargement will be unity, but after passing m the enlargement ratio will be less than unity, as the points where the axis OO_1 intersects the picture ab will be farther from the lens L than twice its focal length. Because of the construction of the tracing the angle α will not change as the lens axis OO_1 and the plane HL will rotate together. But angle β will change and there will be a different enlargement of the whole picture for each point that the picture ab is projected on the optical axis. The new pictures will be made on planes parallel to HL, and at distances below the lens L as required by the particular enlargements.

If the camera lens be used the chord EU will represent twice its focal length, and its front focal plane will be Hb. In this case the new picture will be an infinite enlargement. Therefore, when projecting with c on the axis, the focus of the projector lens must be greater than that of the camera lens, and the new picture will be a finite enlargement.

There is one exception to this, as a lens of one-half the focus of the camera lens can be used to give excellent results. But its use is limited to small tilt angles, and the lens must be stopped to a small aperture. Furthermore, the plane ab must revolve about the point U and at a fixed distance $2f$. Such a picture would be received on a fixed plane parallel to BA and at the distance $2f$ below the lens, and would be the same size as if originally taken in the horizontal plane mT.

By constructing another figure in the manner of Fig. 12, but using a picture at distance F instead of F_N below the camera lens U, it will be found that when m and m_1 are on the optical axis the new picture will be the size as if originally taken in the plane mT. Furthermore, the angles α and β will be equal, and the focus of the projector lens may be less than, equal to or greater than that of the camera lens. When the focii of both lenses are equal, the tilt α of the projector planes will be equal to the tilt angle θ of the camera, as indicated by equation (14). By adopting a lens of shorter focus than that of the camera lens, the projector will be relatively smaller, and smaller tilts will be required in correcting pictures.

From the discussion of Fig. 12 it is obvious that other unknown factors than the tilt angle would be introduced by projecting an oblique picture with any point except the true scale line m in the optical axis

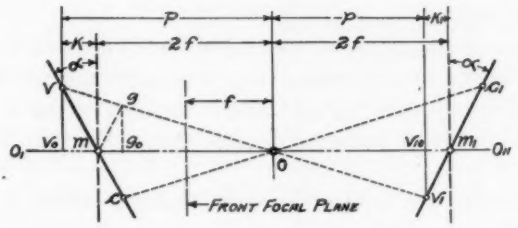


FIG. 13

of the projector lens. The method of horizontalizing an oblique picture and the projector used for the purpose are much simplified by projecting with the true scale line m on the lens axis and in the tilt axis of the object plane of the projector, as shown in Fig. 13.

In Fig. 13, the tilt axes m and m_1 of both focal planes are vertical, and are fixed at twice the focal distance from their respective nodal points of the fixed lens O. The optical axis O_1O_{11} intersects the tilt axes at right angles. Both planes are tilted through equal angles α, but in opposite directions. The image of v is formed at v_1.

Draw a line mg parallel to m_1v_1 and the triangles gOg_0 and v_1Ov_{10} will be equal and Og_0 will equal p. Let vm, vv_0, mg and gg_0 be respectively L, D, $'$ and d, then by similarity of triangles

$$\frac{d}{D} = \frac{p}{P} \tag{16}$$

but

$$\frac{p}{P} = \frac{2f - K_1}{2f + K} = \frac{2f - l \sin \alpha}{2f + L \sin \alpha} \tag{17}$$

and

$$\frac{d}{D} = \frac{l \cos \alpha}{L \cos \alpha}. \tag{18}$$

Substitute nL for l in (17). Combining (17) and (18) will give

$$n = \frac{2f - nL \sin \alpha}{2f + L \sin \alpha}$$

which will reduce to

$$n = \frac{f}{f + L \sin \alpha} \tag{19}$$

so that (19) is the same form as equation (5).

The image v_1 is formed on the oblique plane in the trace of the plane $v_1 v_{10}$ that is conjugate to the plane $v v_0$. Therefore, the oblique lines cv and $c_1 v_1$ may be considered as the traces of two oblique planes in a large number of respectively conjugate planes that are normal to the lens axis $O_1 O_{11}$.

The equivalent focus of the lens of the Brock projector is 9.5″, and all original pictures of the camera are enlarged to the size as would be obtained with a 14-inch lens, resulting in a picture about 12 inches wide and 16 inches long. As there is now a fixed ratio between the focii of camera lens and the projector lens, the relation of the tilt angle α of the projector planes in respect to the tilt angle θ of any picture will be as expressed in equation (14),

$$\sin \alpha = \frac{9.5}{14} \sin \theta.$$

There is no computing of angles in the Brock Process of horizontalizing a picture. Charts and tables have been constructed using some of the equations 5 to 13, but in which the focus of the projector lens and the tilt angles α have been substituted for the camera focus and tilt. The charts are curves drawn on transparent film, and the tilt axis of a picture is determined in reference to the apparent line of flight; the line joining the conjugate centers of a pair of pictures. The charts are laid over each picture of a stereoscopic pair, and indicate the necessary tilts

that will displace the conjugate images of salient points in such amounts and directions as will eliminate excesses in abscissas and ordinates.

The pictures are then placed in a pair of duplicate projectors. The plate-holder of the projector is mounted on a rotator having a horizontal axis, and has means for bringing the center of the picture into this axis. The image of the whole picture appears on a screen that is provided with two sets of very fine parallel lines that are accurately spaced .500 inches apart and intersect at right angles. The intersection of the two main grid lines is in the horizontal axis of the image plane rotator. Ordinates and abscissas are measured in respect to these lines, and means are provided on the image plane rotator for movement of the grid screen in two directions parallel to the two sets of grid lines. When the planes of the projector are normal to the optical axis, the axes of rotation of both rotators will lie in the optical axis. Other means are provided for simultaneously displacing both rotators as the planes are tilted.

By turning one hand wheel both planes are tilted through equal angles α, and rotators of the plate-holder and of the image screen are both displaced equal amounts cm and m_1v_1, Fig. 13, respectively, toward the intersection of the two prolonged tilted planes. The displacing means operate in functional proportion to the tilts of the camera and the projector, and the amount of displacement will always be equal to the product of 14 inches and tan $\theta/2$. Therefore, as the planes are tilted the true scale line m will move into the tilt axis of the focal plane and on the optical axis.

In the Fig. 11, it will be noted that the distances mv and mc are respectively too large and too small in the tilted picture, and that for a horizontal picture the distances would be correct if reversed. That is accomplished in the new picture, as v_1m_1 and m_1c_1, Fig. 13, are now respectively equal to mc and mv, as indicated in the similar and equal triangles. Displacement of the image screen is not necessary to receive the corrected image; it is displaced so that the intersection of the main grid lines will move onto the point v_1, thereby locating the heretofore unknown point where the vertical through the camera lens pierced the oblique picture.

While in this position the grid rotator of each projector, Fig. 14, is rotated until one main grid line of each falls on the conjugate image of the newly found vertical point of each picture. The pictures will then be aligned in their true line of flight.

The images of points of known elevation appear as tiny perforations in the emulsion of each picture. In measuring, the grids are moved until

the nearest line is brought on a point; the points do not move. The movement in thousandths of an inch is read on a dial and added to the amount represented by the number of equally spaced grid lines from the origin. The maximum amount of motion for measuring any distance is not greater than .25 of an inch.

In this manner the abscissas of conjugate points are read on each picture. The pairs of abscissas of conjugate points represent the picture

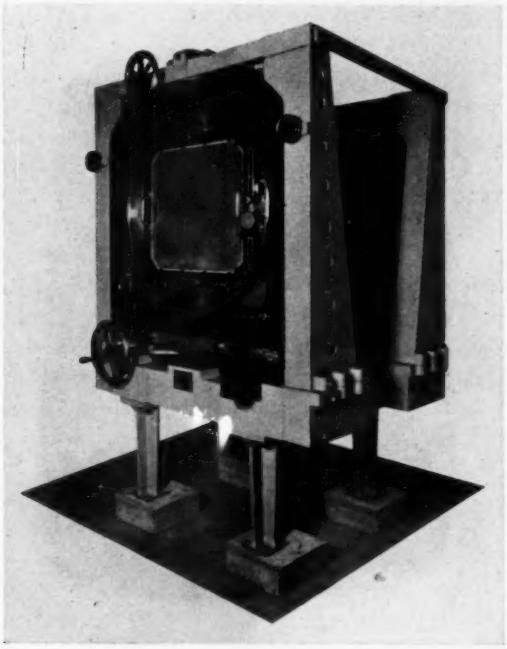


FIG. 14

bases in respect to the planes in which the salient ground points lie. If the value of one base be subtracted from each of the other picture bases, the parallaxes will be found. These are compared with the tabular parallaxes that correspond to the picture base determined from the plotted control and will be found to differ because the new picture bases are now nearer their correct length. Correction of the tabular parallaxes in amounts corresponding to the new picture base will effect very close agreement. Further tilts in one or both pictures in the same or

different axes will bring the desired result. During the operations the ordinates are observed, and from their relations the difference in elevation between the two lens points of the camera is determined. When the parallaxes and ordinates of the salient points are in agreement, the pictures appearing on the two image screens will be horizontal pictures.

Markers are set in relation to the two main grid lines. The grid screens are then removed and replaced by sensitized plates that receive the horizontalized pictures. On the new pictures the intersection of the two lines connecting the marker images locates the trace of the vertical that passed through the camera lens in space.

On another projector positives are made from the corrected negatives and in so doing one of the pair is given the enlargement necessary to bring it to the scale as would exist in both pictures if taken at the same altitude. When the relief of the ground is unusually large in respect to the height of the lens, more than one enlargement is required; as the enlargement is made relative to one ground plane. In all ordinary cases, however, the error introduced by a single enlargement is not appreciable and may be neglected. The pair of pictures are now ready for contouring, which operation has been described.

The lenses of all the projectors were made by the C. P. Goerz American Optical Company, New York. The objectives and the relatively large prisms of the stereoscopes were made of American glass by the Boehmke Optical Company of Philadelphia, and the remarkably accurate grid screens were supplied by Max Levy and Company, of Philadelphia. So that, excepting the camera lenses, all parts of the equipment were made in the United States.

Credit is due Doctor I. C. Gardner, of the Bureau of Standards, for his cooperation in respect to lens tests and for his helpful suggestions relating to them.

When the Brock Process was first presented to the public, doubts, and even ridicule, were expressed in respect to drawing contours from aerial photographs. A relatively large number of test maps were made to overcome this resistance. The first person to contract for a map by this process frankly stated that he was advised against it, but as he was unable to obtain what was desired by ground methods, he decided to try the aerial method. Subsequently, he volunteered the information that by use of the aerial map his construction plans were changed, effecting an estimated saving of about $750,000.

The statement has been made that while the most accurate maps are produced by the Brock Process, their cost is the highest. If the cost is

high, then the statement also suggests the reason, as accuracy is always a cost factor of any article. But it also suggests that a map by any method may be relatively more costly on account of inaccuracies, which will be more evident when large-scale government maps are made to meet the apparently increasing demand. However, regardless of methods, or of articles produced, no production can be effected at low cost if the equipment is idle sixty-five percent of its time. Unfortunately, there has been no available market that would permit of operating the Brock equipment as was intended. The question arises whether expenditures for further development of the art by private interests are warranted.

The National Defense Act of our government is broadly and wisely interpreted by its military departments. The different branches of these departments invite private interests through contracts and other means to help in the development and production of materials of war. In line with this policy the Engineer Corps has made extensive studies and developments in respect to the use of aerial mapping methods and instruments best suited to its needs. That its work has been planned and executed well is evidenced in the excellent cameras made by the Fairchild Camera Corporation. Furthermore, the Engineer Corps also makes contracts with private concerns for maps of some of the limited areas under its control. These contractual relations with private concerns have aroused interest in the Army's needs, resulting in mutual benefit to the Army, to industries and to the whole country.

However, the particular department of our national government that is most responsible for the production of maps of its vast areas, is not permitted by law to make contracts with private concerns for making topographic maps by aerial photographic methods. Is it not reasonable to expect that such contracts, if permitted, would be in the interest of further development of aerial mapping, in the interest of the particular department, and in the interest of the whole country?

AERIAL STEREO-PHOTOGRAPHIC MAPPING INSTRUMENTS AND METHODS*

By C. H. Birdseye
[Pres. Aerotopograph Corporation of America, Washington, D. C.

Received November 19, 1931]

Introduction

It is somewhat presumptious for one who has only an elementary knowledge of optics to address the Optical Society. However, the Chairman of your Program Committee assured me that what he wanted was a short paper on the application of aerial photography to mapping. Such a program is a difficult task; because, first, there is a lot about the subject that I do not know, and second, the subject is too broad to be covered adequately in a short paper.

I shall therefore limit my remarks to the application of aerial photography to stereo-topographic mapping, and will describe very briefly some of the methods and instruments with which I am familiar. I shall then suggest certain needed changes in American instruments and methods, and certain new equipment which I think should be made in the United States.

Aerial Cameras

The aerial camera equipment required for making high grade contour maps by stereoscopic use of aerial photography is quite different from that which will suffice for the making of mosaics or the taking of photographs to be used in map compilation by other methods. In general the lenses must be relatively free from distortion throughout a field of at least 25° from the optical axis, and any errors of curvature within this field should be as uniform as possible. The focal lengths should be designed to cover the requirements of large, medium and small scale mapping. In my judgment these requirements would be met adequately by lenses ranging in focal length from 20 inches down to 4 inches, perhaps stepping down in intervals of 4 inches; for example, 20, 16, 12, 8, and 4. I know that this suggestion may present unsurmountable difficulties, particularly in the case of a 4 inch lens which will cover a reasonably large negative adequately. Nevertheless, there is a demand for adequate equipment for small scale mapping, such as the standard maps of the Geological Survey and the tactical maps of the Army, and in order to make these economically by stereoscopic methods it is necessary

* Paper presented at the Annual Meeting of the Optical Society of America at Rochester, New York, on October 24, 1931.

to cover an extremely large area in a single exposure. This requires flying at high altitude with a short focal length lens. I suppose it is out of the question to expect to secure a 4 inch lens that will cover a 7 by 9 inch or even a 5 by 7 inch negative, but such a lens would be ideal for this small scale mapping, and used at an elevation of sixteen thousand feet above ground would give a photo scale of 1:48,000, which is the scale of compilation of the Geological Survey mile to the inch maps. Under such conditions, a 5 by 7 negative would cover 20 square miles,

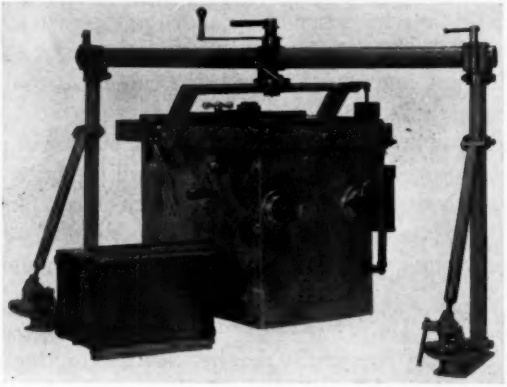


FIG. 1. *Brock aerial camera.*

and a 7 by 9 negative would cover 36 square miles at a single exposure. Fairchild has recently adapted a 6 inch lens to a 7 by 9 inch negative, and while we do not know that the distortion of the field is small enough for stereoscopic mapping, we do know that the images are sharp in the corners of the negative, and I am optimistic enough to hope that lenses of even shorter focal lengths can be made to cover negatives at least 7 by 7 inches in size. The solution may be in the multiple lens camera, for we have demonstrated that elevations can be determined and both vertical and horizontal control carried forward by stereoscopic use of negatives taken with the Bagley four lens camera. However, the expense of such an instrument and its transformer, together with the difficulty of transforming the wing negatives, makes the use of single lens photographs advisable for civilian activities.

Two other requirements for stereoscopic mapping are a "between the lens" shutter of at least 80% efficiency, and a glass pressure plate which

holds the negative absolutely flat and in a plane perpendicular to the optical axis of the lens, and on which are engraved the principal point and the marginal registration marks required. This pressure plate must of course be rigidly attached to the frame of the camera, and not fitted in the removable magazine. I shall not attempt to prove my case for the between the lens shutter vs. the focal plane shutter, but shall merely cite the experience of the Army Air Corps, the Corps of Engineers, the

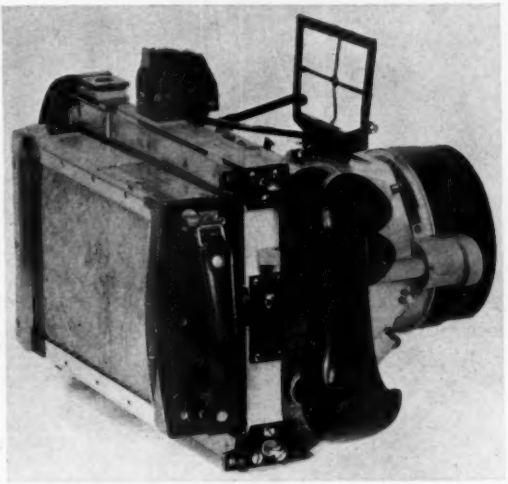


FIG. 2. *Hugershoff aerial surveying hand camera. With glass plate magazine.*

Geological Survey, and most of the mapping agencies in Germany, all of which use the between the lens shutter for high grade map work.

For large scale map work, much longer focal length lenses are required, and for city work especially it is desirable to have cameras with glass plate magazines so as to eliminate film distortion. We have been using German made film, which is claimed to be uniform in shrinkage. Tests made by the Bureau of Standards have indicated reasonably uniform shrinkage, but even at that we feel that it is not good enough for precise work. However, I think that, next to meeting the small scale mapping problem, our greatest need is for cameras with lenses of 20, 16, and 12 inch focal lengths with plate magazines holding at least forty-eight 7 by 9 inch plates each. Of course, such cameras should also be

fitted with film magazines. This again may be a wild dream of mine, but I am citing an ideal and I believe the solution is easier than the short focal length "dream".

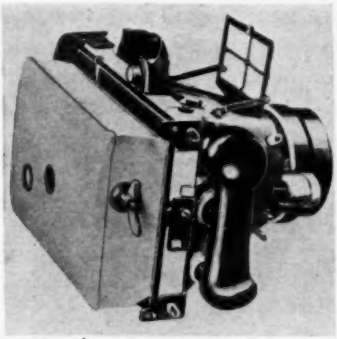


FIG. 3. *Hugershoff aerial surveying hand camera. With roll film magazine.*

Probably most of you are familiar with the different types of cameras used in stereoscopic mapping. The following are a few of the best known.

The Brock Aerial Camera is a single lens camera designed for focal

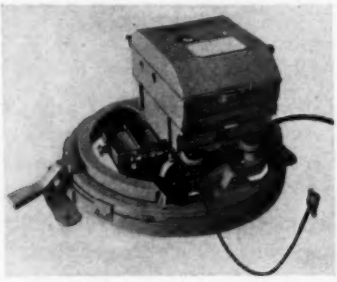


FIG. 4. *Hugershoff automatic aerial surveying camera.*

lenses ranging from 6 to 12 inches, and using a plate magazine accommodating 48 glass plates, size 5 by 7 inches. Separate magazines are carried for additional exposures. Fig. 1 illustrates this camera.

The Hugershoff Aerial Surveying Cameras are of three types, as follows:

a.—Hand Surveying Camera, focal lengths 18 and 23 cm and nega-

tive sizes 13 by 18 cm and 18 by 24 cm respectively. Both are equipped with glass plate magazines accommodating 6 plates and with roll film magazines affording 55 exposures. Additional magazines of both types are provided for additional exposures. The camera is designed for hand operation only. Fig. 2 illustrates the camera with the glass plate magazine and Fig. 3 with the roll film magazine.

b.—Automatic Aerial Surveying Camera, focal lengths 13½ and 18 cm and negative sizes 13 by 13 and 18 by 18 cm respectively. The camera can be operated automatically by a motor (wind or electric) which

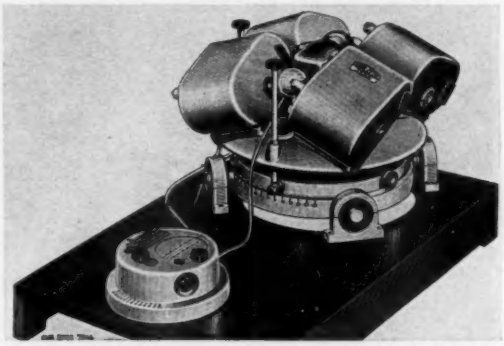


FIG. 5. *Zeiss quadruplex surveying camera.*

winds the film, operates the shutter, exposes the negatives and controls the overlap, or it can be operated by hand. This camera is equipped only with roll film magazines, each affording 375 exposures. Additional magazines are usually not supplied, as the magazine capacity is so large, and it is relatively easy to reload in the air. Fig. 4 illustrates this camera.

c.—Hugershoff Reconnaissance Surveying Camera, focal length 6½ cm and negative size 6 by 6 cm. This camera is designed for use with the Aerosimplex, referred to below, on extremely small scale mapping. The camera has a special device which permits photographing two parallel strips with proper lateral overlap. This is accomplished by alternately tilting the camera to the right and to the left transverse to the direction of flight, so that the successive exposures belong alternately to the right and left strips of photographs. It therefore fulfills some of the requirements of a multiple lens camera. The camera and view finder are fully automatic in operation. It uses a roll film magazine affording over 300 exposures.

The Zeiss Surveying Cameras are also of several types, as follows: A single lens automatic surveying camera with focal length of 21 cm and employing a single roll of film, taking 285 photographs approximately 7 by 7 inches in size; a duplex surveying camera, with focal length 13½ cm, each magazine carrying a roll of film sufficient for 460 photographs

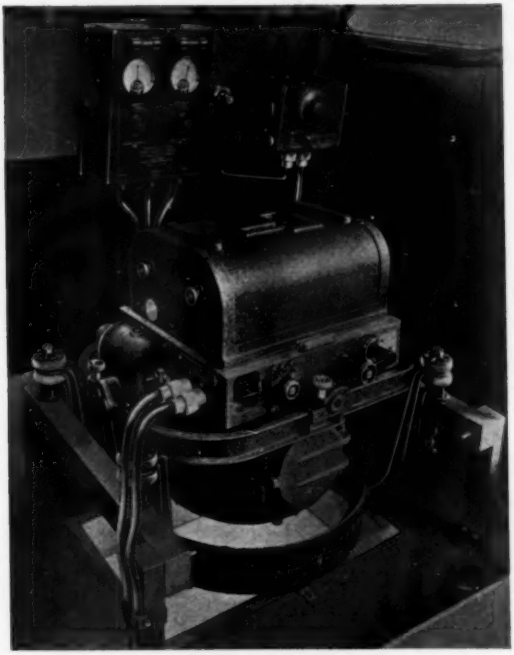


FIG. 6. *Fairchild K-8A aerial camera.*

of size about 5 by 5 inches; and a quadruplex surveying camera, focal length 13½ cm. In this model the four magazines are grouped in two pairs so that each pair provides 460 photographs about 5 by 10 inches in size. These cameras are all fully automatic and are equipped with adjustable mounts and various combinations of wind and electric motors. (Fig. 5 illustrates the quadruplex camera.)

The Wild Surveying Cameras, made by Henry Wild in Heerbrugg, Switzerland, are somewhat similar to the Zeiss single chamber camera. In Switzerland most of the contour map work is accomplished by means of a photo theodolite from ground stations, and aerial views are used

largely in mapping the non-mountainous areas and in filling in the topography of valleys.

No mention of aerial surveying cameras suitable for stereotopographic work would be complete without reference to two other series, both made by the Fairchild Aerial Camera Corporation. This company has developed a number of different types of single lens aerial surveying cameras, the latest being constructed on Army Air Corps specifications

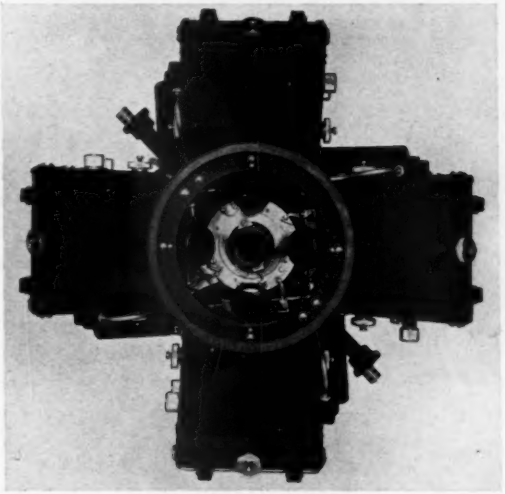


FIG. 7. *Bagley five-lens camera.*

and known as the K-8A aerial camera. This fully automatic camera is equipped with lenses of focal lengths of $8\frac{1}{4}$, 10, 12, 20 and 24 inches, and uses an interchangeable film magazine accommodating a roll of 110 exposures, affording negatives size 7 by 9 inches. Fig. 6 illustrates this camera.

Major James W. Bagley, Corps of Engineers, in collaboration with the Army Corps and the Corps of Engineers at Wright Field and with the Fairchild Aerial Camera Corporation, has developed three types of multiple lens cameras, with three, four, and five lenses. In all of these cameras, the central lens points vertically downward and the others are grouped at angles of 43° from the vertical. In the three-lens camera, 190 exposures from each lens are made on a single roll of film; the focal length of the central chamber is 16.5 cm and the focal length of the ob-

lique chambers is 18.4 cm. In the four-lens camera, 190 exposures from the central and two side lenses are made on a single roll of film and 190 exposures from the fourth lens are made on a separate roll of film carried in a separate magazine, the focal length of the central chamber being 16.5 cm and the focal length of the three oblique chambers being 18.4

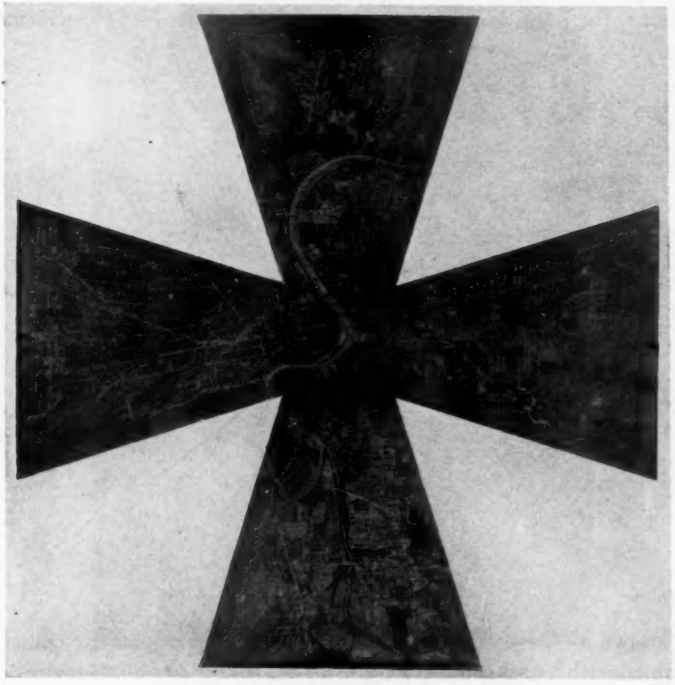


FIG. 8. *Transformed five-lens photograph.*

cm. In the five-lens camera, 190 exposures are made from five individual rolls of film carried in five separate magazines, the focal length of all five lenses being 15 cm. Fig. 7 illustrates the five-lens camera and Fig. 8 shows a transformed five-lens photograph.

RECTIFYING CAMERAS

The condition which gives the most trouble in precision work with aerial photographs is tilt in the negative. It is impossible to keep the optical axis of the camera vertical. Gyroscopic attachments have not

been successful because of the lag, and level bubbles fail because of inertia. In most of the European stereoscopic plotting instruments tilt in

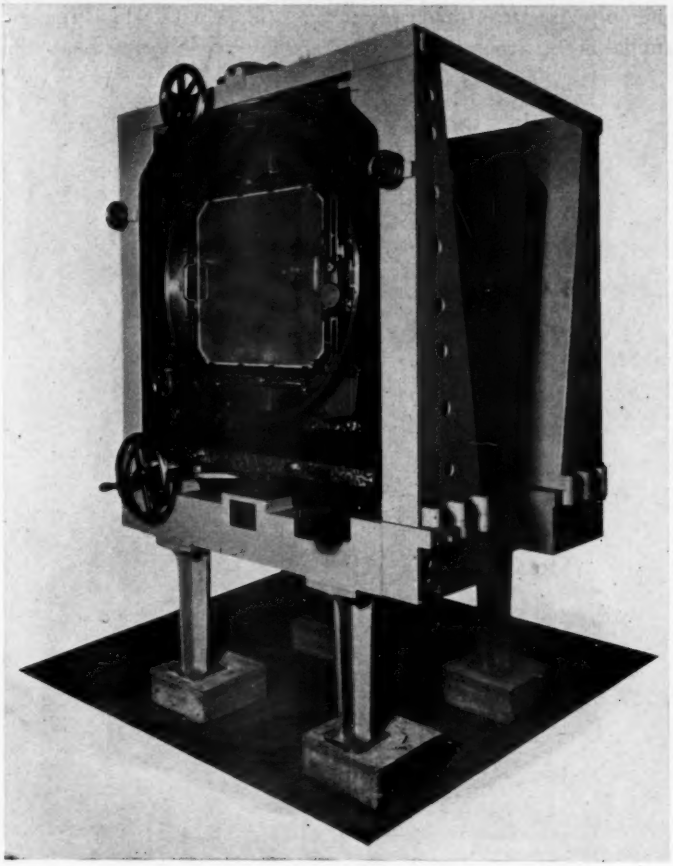


FIG. 9. *Brock projector.*

a negative is eliminated by the setting in the plate holder, but in flat bed instruments of the stereo-comparator type, it is necessary to eliminate tilt in each negative. For this purpose there have been designed rectifying cameras, which are projecting cameras in which the plane of the copy plate or board can be tilted at any angle from the plane of the negative. The condensers and the projection lens must be as free

from distortion as possible, and if the tilt in the negative is large, facilities must be provided to tilt the lens as well as the copy board so that the images in the different parts of the copy will be sharp.

The only American-made rectifying camera with which the speaker is familiar is the Brock Projector. This is a very elaborate, heavy instru-

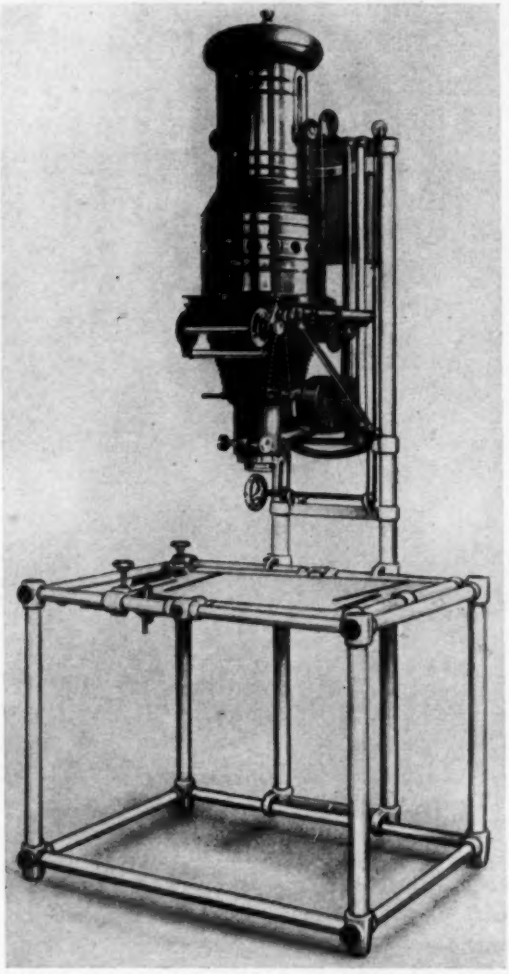


FIG. 10. *Hugershoff rectifying camera.*

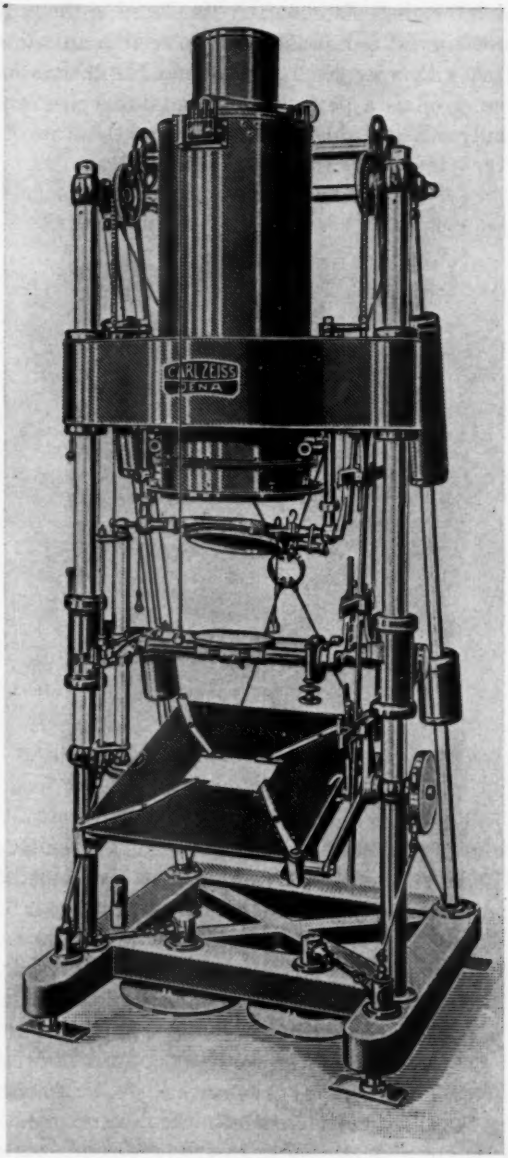


FIG. 11. *Zeiss rectifying camera.*

ment in which the glass plate negative is placed in the projecting camera box and the sensitized glass plate is placed in an adjustable frame which is fitted with very accurate slow motion devices for focus, tip, and tilt. The result is a perfectly horizontalized glass positive plate, which is usually enlarged about two times from the scale of the original negative. Fig. 9 illustrates this instrument.

FIG. 12. *Fairchild automatic interval finder.*

The best known European rectifying cameras are the Hugershoff and the Zeiss. The Hugershoff Rectifying Camera is designed for use with negatives up to 18 by 18 cm and for enlargements up to 1:3.5. Facilities are provided to tilt the copy board in two planes at right angles to each other, and to tilt the lens several degrees from the vertical. Convenient fast and slow motion devices are provided for scale ratio and focus. The instrument is relatively light and portable. Fig. 10 illustrates this instrument.

The Zeiss Rectifying Camera is somewhat similar to the Hugershoff camera, except that the objective lens in the projection device is swung in a frame separate from the housing of the projector, while in the Hugershoff camera the objective lens is fitted in a ball and socket joint at

the lower end of the projector housing. Neither of these cameras is fitted with a shutter, and in working in our own laboratory, we have attached a shutter to the Hugershoff rectifying camera. Fig. 11 illustrates the Zeiss rectifying camera.

AUTOMATIC VIEW FINDERS

The securing of proper overlap between successive photographs, as well as counteracting drift and crab, gives an inexperienced photographer considerable trouble. Many devices have been used to solve these difficulties. Most American photographers use several instruments, including a visual vertical view finder requiring the spotting of features on the ground ahead in a ground glass grid, a drift indicator, an intervalometer, a stop watch, etc. Fairchild has developed an Automatic Interval Finder which is operated by the same motor which drives the camera, and automatically corrects for ground speed and crab and insures the proper longitudinal overlap. This is accomplished by a wire traveling underneath the ground glass surface, adjustable to keep pace with the travel of images on the ground. Fig. 12 illustrates this instrument.

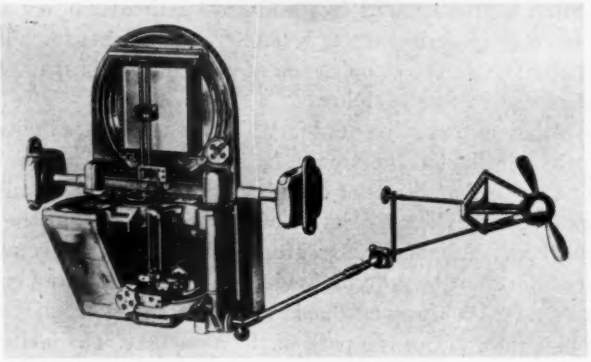


FIG. 13. *Hugershoff quo vadis.*

The Hugershoff Automatic View Finder accomplishes the same results by means of an endless screw placed in the center of the ground glass surface in the direction of the line of flight. Screws of different pitches are designed for different altitudes and overlaps. This view finder also is driven by the same mechanism which drives the camera.

An experienced aerial photographer has much less trouble with longitudinal overlap than with lateral overlap. Proper performance as to the former is largely his function, while successful side overlap is largely the responsibility of the pilot. In flying over sectionized country parallel to long, straight roads or fences the pilot has little trouble. Moreover, if a good flight map showing all of the prominent ground features is available and there is not too much relief, most experienced mapping pilots are able to fulfill the lateral overlap requirement. But in rough, unsectionized country, where good flight maps are not available, the best pilot is often in trouble. The fact that most estimates of aerial photography for map work include at least 10% of reflights for filling gaps between flights, and the examination of most indices of map photography, indicate the waste in flying.

There is therefore a crying need for an automatic course indicator and plotter which will plot the trace of the path of the aeroplane on a gridded paper so that the pilot can "lay down" the next parallel flight in proper position. The only device of this kind known to the speaker is the Quo Vadis, designed by Dr. Hugershoff. This is a fully automatic instrument built on the automatic view finder principle and controlled by a compensated compass needle, in which a drawing pencil is actuated so as to plot the trace of the path of the aeroplane. The instrument is driven by a separate wind motor and is designed for installation in the pilot's cockpit. Fig. 13 illustrates this instrument. The instrument is reported to have functioned perfectly in Europe and South America when used in German aeroplanes, but unfortunately it failed on the only tests made in the United States, due probably to lack of compensation of the compass needle in American aeroplanes.

STEREOSCOPIC MEASURING AND PLOTTING INSTRUMENTS

My discussion of instruments of this kind must necessarily be very brief and will omit any references to simple stereoscopes or to instruments of the stereocomparator type.

The Brock Stereometer.—The only American-made instrument of this type is the Brock Stereometer, developed by a firm of engineers in Philadelphia. In as much as this program provides for a paper to follow on the Brock Aerial Mapping Process, I shall not attempt to describe the instrument, except to point out that the instrument is a flat-bed measuring stereoscope in which the photographic negatives are first rectified to the horizontal and then printed in the form of glass positive plates. Stereoscopic pairs of these plates are then placed in the stereom-

eter and the contours as well as all the other map features are then drawn by hand on a transparent medium placed over one of the plates. The perspective drawings are then transformed to a true orthogonal projection in a combination projection-tracing table device and the transformed tracings are assembled on the base map sheet, usually by the radial line method. Fig. 14 illustrates this instrument.

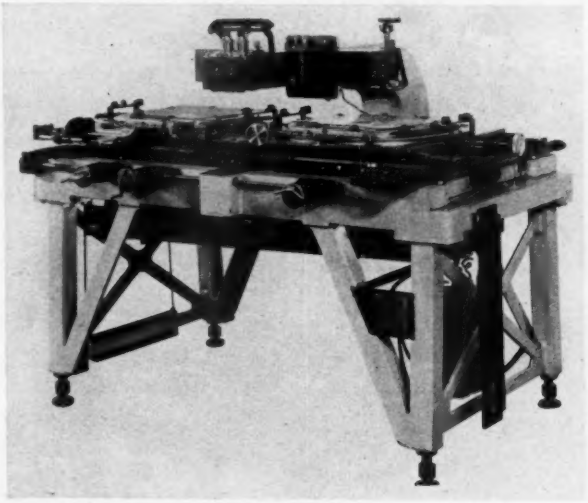


FIG. 14. *Brock stereometer.*

The Hugershoff Aerocartograph.—This is the instrument which I know best, as it is the one with which I have been working for several years. The instrument is a combination viewing, measuring and plotting instrument, by means of which contour maps are drawn in true projection directly from untransformed aerial photographs. One of the principal features of the instrument is the facility of extending control optically, thereby reducing the required ground control to a minimum. A brief and extremely crude description of the instrument is as follows:

Two overlapping photographs (negatives or glass positives) covering in part the same terrain are placed in the two plate holders of the instrument and adjusted to each other so that they form a perfect plastic model when viewed through the binocular viewing device. Various adjustments permit the rectification of different tilts and different scales in the two photographs. The optical model is then adjusted to the hori-

zontal plane and to the ground control which has been plotted on the map sheet. This sheet is placed on a drawing board in the base of the instrument, or on an adjacent drawing table, known as the coordinatograph, which is geared to the aerocartograph.

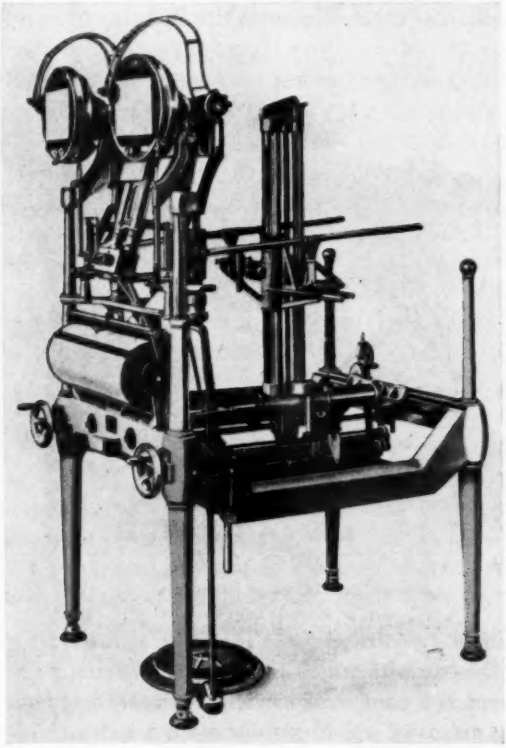


FIG. 15. *Hugershoff aerocartograph.*

In each viewing telescope there is an index mark or cross hair which in binocular vision is fused into a single index or floating mark, and can be moved in the three coordinates of space, the X, Y, and Z coordinates, by means of two hand wheels and a foot wheel. The operator by means of this floating mark traces over the model, following all the roads, streams, contours, and other features desired in the map. The pencil in the plotting device which is geared to the coordinate system plots the trace of the floating mark in true projection and common scale. Thus

the map is made in one operation directly from the photographic data. Of course, the writer has omitted all the details, particularly those of adjustments of the plates and the requirements of ground control, the latter being the horizontal positions and elevations of three points in the first and last overlapping pair in each strip of photographs. The aerocartograph performs equally well with aerial or ground photographs, either vertical, horizontal, or oblique. This instrument is illustrated in Fig. 15 and 16.

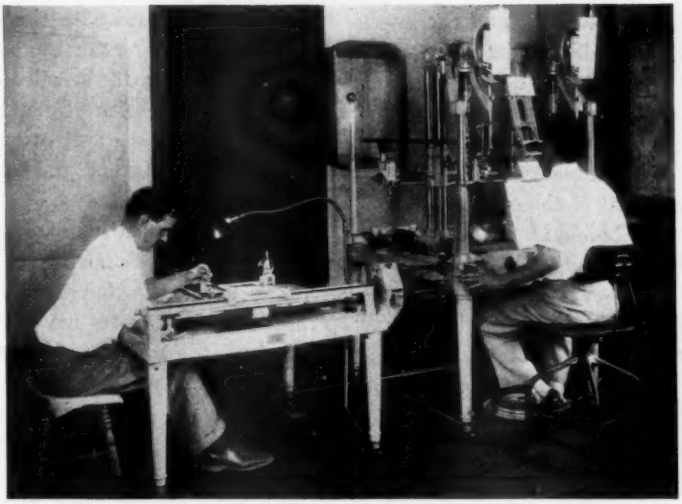


FIG. 16. *Hugershoff aerocartograph and coordinatograph.*

A complete description of the construction and operation of the aerocartograph is given in a mimeographed pamphlet prepared by the U. S. Geological Survey, entitled "The Construction and Operation of the Hugershoff Aerocartograph." The writer has also prepared a paper for the American Society of Civil Engineers entitled "The Aerocartograph Method of Photo-Topographic Mapping," which is published in Proceedings for January, 1931.

The Hugershoff Aerosimplex.—Dr. Hugershoff has perfected another stereoscopic plotting instrument known as the Aerosimplex, designed for small scale mapping of the reconnaissance type. The method of operation is based on the principle of twin projection first utilized by Scheimpflug in 1897, but with the essential difference that the two

overlapping photographs are not projected upon one another but upon separate projection screens so that the entire overlapping image field is available for normal stereoscopic observation. Certain limitations are, of course, connected with such projection, and the method is limited in use to photographs whose optical axes diverge only a few degrees from the vertical and in which the differences of elevation in the terrain are small in relation to the altitude of the camera.

There are three principal parts to the aerosimplex:

1.—The horizontal and firmly fixed support for the two ground glass projection screens, and the lateral drawing surface level with them.

2.—A horizontal base bar, movable in the distance direction by means of a foot plate, carries the projectors, which can be adjusted at will along three axes of coordinates at right angles to one another and can at the same time be tilted and tipped. The base can be turned about two axes which are at right angles to one another, affording transverse and longitudinal tilt of the optical model.

3.—A binocular pointing telescope, which is equipped with modern devices for adjusting the eyepieces to the optical peculiarities of the operator's eyes and with a mechanism for switching the stereoscopic effect from normal to pseudo vision so that successive plates may be inserted in either plate holder and made to appear in proper sequence.

The plotting of this stereoscopic model is accomplished by means of two rigidly connected pointers lying directly upon the projection screens. They can be set to any point of the projection screens by an unrelated parallel motion. A pencil is fastened to the side of the same parallel motion, and this reproduces the motions of the pointers. Hence, if the stereoscopic image of the pointers (the floating mark) seemingly touches any point of the surface of the model, a contour line is obtained by moving the floating mark so that it is always in apparent contact with the surface of the model. If a higher or lower contour is to be traced, the optical model is advanced or withdrawn by the proper movement of the base by means of the distance driving floor plate.

The orientation of the plates to one another and to the drawing surface, which represents the horizon, is accomplished in the same manner as, for example, in the aerocartograph:

1.—The stereoscopic model is obtained by systematic adjustment of one projector in relation to the other until all vertical parallaxes have been eliminated.

2.—The scale of the map is obtained by a proportional change of the

base components, until a stereoscopic distance is equal in scale to the distance between the corresponding object points.

3.—Horizontalization of the model at true scale is accomplished by tilting and turning it until three points in the model forming a triangle show the same elevation differences from each other as the correspond-

FIG. 17. *Hugershoff aerosimplex.*

ing object points have on the ground, whose elevations have been determined by terrestrial methods. This procedure can be carried out much more quickly than in precise surveying instruments, not only because of the unrelated movement of the stereoscopic pointer, but above all because of the joint tilting and turning of the two projectors, employed here for the first time.

Generally speaking, the procedure of orientation, when there is a consecutive series of photographs with an overlap of more than 50%, is necessary for only the first pair. The orientation of the third photograph to the already oriented second one, the fourth to the third, etc.,

is carried out in the aerosimplex just as in the aerocartograph in a purely optical manner.

Diapositives from negatives taken with any aerial surveying camera are used, although it is preferable to use photographs taken with the special camera provided for this instrument, with the small 6 by 6 cm negatives and lens of focal length of $6\frac{1}{2}$ cm. If other negatives are used, they should be reduced to a 6 by 6 cm size by means of a special reduction camera especially adapted to the exposure camera. The special

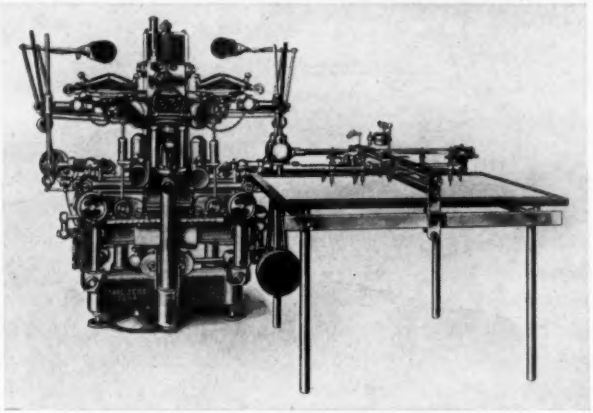


FIG. 18. *Zeiss stereoplanigraph with duplex plate holders.*

lenses used in projection generally have a focal length of 4.0 cm, while the principal distance of the projectors is 6.5 cm. The mean distance (the distance of greatest definition) from the projectors to the projecting surface is 10.4 cm. However, as a consequence of the definition of depth in the projection lenses used, the definition is amply sufficient for stereoscopic measurements between the distances of 7 and 13 cm. Therefore, for example, with a mean altitude of 2000 meters, the terrestrial differences in elevation may be up to 600 meters. Fig. 17 illustrates this instrument.

The Zeiss Stereoplanigraph.—The firm of Carl Zeiss has developed several different types of stereoscopic measuring and plotting instruments, but the latest development is the new stereoplanigraph, which was first exhibited at the International Congress at Zurich in 1930. The different models of the stereoplanigraph are designed for use with the three types of Zeiss surveying cameras, viz., the single lens, two lens

and four lens cameras; therefore the different models provide pairs of plate holders of the single, duplex and quadruplex type. In the multiple plate holders, the combinations of plates are adjusted in exactly the same position that they held in the camera, and the assembly in each pair of plate holders is then adjusted one to the other for stereoscopic effect, so that in viewing the stereoscopic model formed by the combination of plates, the operator is able to pass from one plate to another without breaking the model, and apparently sees a perfect model as though it were viewed from a single pair of plates. All of the newer types

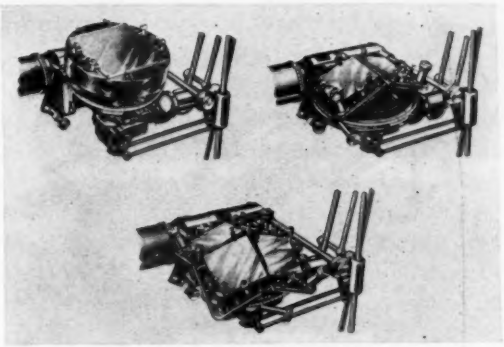


FIG. 19. *Zeiss single, duplex and quadruplex plate holders.*

of the stereoplanigraph embody four main parts, viz., a projecting system, consisting of a pair of plate holders with the accompanying attachment for adjustments, illumination, and projection; a measuring system, consisting of a combination of bars and lenses which are arranged to cover a three dimensional coordinate system and permit stereoscopic measurement by the usual employment of a floating mark; the viewing system, which consists of a binocular telescope and an elaborate optical train in which it is possible to switch a pair of prisms so that the images on either plate may be viewed with either eye. This permits the carrying of control optically by replacing one of the plates of a stereoscopic pair which has already been adjusted by the next succeeding plate in the series, and adjusting the last plate to the one remaining in the instrument which has not been disturbed; and the drawing device, which is a plotting table geared to the coordinate system of the main instrument and arranged in duplex form, with two drawing devices carrying out identical movements but arranged in such a way as to have one

of them available for the use of the stereoscopic operator and the other for use by his assistant. Thus the observer can either work alone and watch his drawing without leaving his seat, or his assistant can observe the drawing and make the necessary notations and corrections, thus leaving the observer free for his stereoscopic operations. There is a gear ratio box between the drawing table and the main instrument so

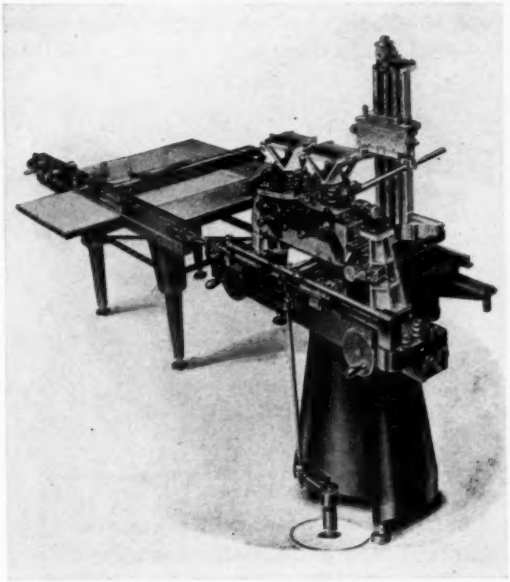


FIG. 20. *Wild autograph.*

that the map can be drawn on different scales, such as ratios of 1:1 and 1:5 and vice versa from the scale of the photographic plates. All of these devices except the use of multiple plates are incorporated in the aerocartograph, although the optical and mechanical arrangements are quite different. Fig. 18 illustrates the stereoplanigraph with the duplex plate holders and Fig. 19 illustrates the single, duplex and quadruplex plate holders.

The Wild Autograph.—The Autograph was first designed principally for stereoscopic work with photographs taken from ground stations, but was adapted also for work with vertical or oblique aerial views. The instrument is entirely different in appearance from the aerocartograph

or the stereoplanigraph, but the basic principles are much the same. In general, facilities are provided for orienting and adjusting the plates one to the other, to the horizontal and to the map scale, and the "floating mark" is actuated in the three coordinates of space by means of two hand wheels and a foot plate. As in the stereoplanigraph, the plotting is always accomplished in a separate table. Fig. 20 illustrates this instrument.

The Nistri Photo-cartograph.—In Italy considerable advance has been made in stereoscopic measuring and plotting, the principal development being represented by the Photo-cartograph, invented by Umberto Nistri and operated by the Societa Anonima Rilevamenti Aerofotogrammetrici in Rome. This instrument is of the camera plastica type, in which the images from the two plate holders are thrown on an adjustable screen and the coincidence of corresponding images is determined by a flickering device by means of which light is cut off first from one projector and then from the other. The screen must be moved for each plane of elevation and in each plane all coincident images will lie on a contour represented by the screen setting. The trace of each contour is transferred to a drawing board by a pantograph system.

The Barr and Stroud Photogrammetric Plotter.—In England the latest development is the Photogrammetric Plotter. This is a very large and cumbersome looking instrument of the camera plastica type but one which is considered quite simple in operation. The screen on which the two projections are superimposed is fixed and the two projectors are moved in the three coordinates of space by three movements, two of which are imparted to the drawing board. The British Air Survey Committee and the Ordnance Survey have apparently given up the use of this instrument on small scale topographic mapping, feeling that it is more economical on such work to measure elevations in a stereogoniometer and then plot details by interpolation by means of transparent grids placed over each photograph in a simple topographical stereoscope. For this purpose they use the Fourcade Stereogoniometer and the Barr and Stroud Topographical Stereoscope. All of these instruments are described and illustrated in the Geographical Journal for February, 1930 in an article by Captain M. Hotine, entitled "The Application of Stereoscopic Photography to Mapping."

In conclusion, I cannot refrain from expressing the hope that more American inventors and manufacturers will interest themselves in the development of these automatic measuring and plotting instruments.

The heavy duty of forty-five percent on the importation of foreign made instruments of this kind makes their purchase almost prohibitive, except by governmental agencies. The field of usefulness, especially in small scale mapping, is large and an American made instrument which will reduce the ground control operations to a minimum and could be sold at reasonable cost would do much to expedite the completion of the topographic mapping of the United States. Moreover, I hope that more of our universities will follow the example of Syracuse University and offer thorough training in stereoscopic mapping.

AN APPARATUS FOR MOTION PHOTOMICROGRAPHY ON 35 MM FILM*

By R. P. Loveland

[Kodak Research Laboratories, Rochester, N. Y.

Received November 24, 1931]

Under the necessity of taking motion photomicrographic scenes for production purposes, we devised and set up an apparatus for the purpose, to use 35 mm film. Some scenes were to be at high magnifications under critical conditions so that although economy was a chief consideration, no essential necessary for quality of image should be sacrificed. Some of the work was to be done at an institution some miles from the place of final installation, so a semi-portable set was required.

Requirements

In ordinary photomicrography, one picture is usually all that is desired for any one set-up of conditions which, therefore, need only remain satisfactory and constant for the duration of one exposure time. In motion photomicrography, however, a continuing succession of pictures is desired, and conditions must remain satisfactory for a considerable length of time. These include not only conditions for critical illumination, but freedom from vibration, maintainance of critical focus, *etc.* Moreover, there is at least one machine in the system that is operating with intermittent motion, and there is usually a motor included which is acting as a source of vibration.

It is obviously necessary that there should be no physical contact between the microscope and the camera; in fact they should be mounted on completely separated supports. For work at high magnifications, it is probably wise to separate all of the units and a magnetic clutch between the motor drive and the camera is the ideal. A belt or a shaft containing two universal joints and a well-oiled sliding connection is, however, quite satisfactory.

Conveniences so great in motion photomicrography as almost to be necessities are the power to see the field while it is being photographed, and to focus the image accurately on the photographic film, to notice if it goes out of focus, or to keep it in focus over long periods. This requires some sort of beam splitter with a plane that can be observed visually and that is so adjusted that when the image is correctly focused

* Communication No. 490.

on the film, the other component is also correctly focused on it. Really, more than the camera field should be seen through the visual eyepiece so selections can be made during photography. Moreover, *any* observer should be able to place the same plane of "best focus" on the film plane so that observations during extended photography of growth of organisms may be done in shifts. It is convenient to have a pair of cross hairs in the plane of the correct visual focus as well as the lines that indicate the limitations of the camera field, so that the best focus may be obtained in the middle of the field with high power apochromats. Now, unless the eyepiece through which these lines are observed, is made adjustable for focusing upon them, very few observers will obtain exactly the best focus on the film. Certainly it is more satisfactory for each individual observer to focus the eyepiece exactly on the cross hairs before focusing the microscope image, than it is to attempt to place the image correctly by the method of parallax with slightly out-of-focus images, especially while attempting to keep the focus constant over long periods.

Since it is often desired to operate the mechanical stage during photography or even perform manipulations upon the stage itself, it is absolutely impractical to have the microscope itself supported on a floating system as is the usual case in still photomicrography. Instead of standing on rubber or being supported on springs, for perfectly general use it must be firmly fastened to a solid, stable support which is itself located in a spot not subject to appreciable vibrations. The microscope stand itself must, therefore, be selected with more than usual care for its stability and also for its ability to stay in focus over long periods. The various microscope stands available vary enormously in the degree in which a highly magnified image is affected by external vibrations. As for staying in focus over long periods of time, that also varies much with the type of stand, but is dependent to a surprising degree upon the constancy of the temperature.

A smoothly working mechanical stage is, of course, essential. If images are expected to stay in focus at high magnification, the slide or cell must rest directly on the stage and not be held by the arms of a mechanical stage. For the purposes of motion photomicrography, the present design of the horizontal microscope stage which consists of a shelf supported on one edge, is very undesirable. It can hardly be touched without affecting the image. For such purposes the stage should probably be a sturdy tripod resting directly on the main support. It is rarely used in other than the horizontal position.

For the same reason of stability the camera should be comparatively wide and low, having the width of the base greater than the height to the lens, unless supported on its face, and should work smoothly and easily. Otherwise, it may become a secondary source of vibrations.

The camera support for 35 mm motion photomicrography is a special problem that requires features not obtainable—so far as we know—in any one commercial apparatus:

(1) It must be very stable.

(2) It must hold the camera firmly.

(3) Although independent of the microscope support, it must hold the camera close to the microscope.

(4) It must be massive with respect to the mass of the camera, and not easily affected by vibrations due to cranking the camera.

(5) With a vertical microscope axis, the light lock between microscope and camera should move in and out vertically. (Otherwise, there is the extreme inconvenience of removing the camera each time the height of the tube is changed a little.)

(6) It should be possible to raise or lower the camera vertically at least enough to clear it of the light lock, and to accommodate the different heights of the microscope tube with different optical systems.

(7) It should be possible to swing the camera out of the way for visual work and yet be possible to swing it back quickly into its exact optical position again.

In any extensive work in motion photomicrography, a large range of camera speeds will certainly be wanted. This requires a motor drive and reduction unit which must be carefully planned to reduce the vibrations emitted. Since the microscope must be bolted down without the usual vibration absorbers, it is well to mount the camera drive on a "floating system." This eliminates the transmission of vibrations through the floor.

DESIGN OF APPARATUS FOR THE PURPOSE

An observation eyepiece with beam splitter was adopted that was essentially the same as that designed by Mr. C. Tuttle of the Kodak Research Laboratories,[1] but made by the Bausch & Lomb Optical Company with dimensions and optics to suit the 35 mm camera. The eyepiece was made focusable on the cross hairs in the visual tube as described on page 2, and the shift observers have come to the same focus

[1] C. Tuttle, *Motion Photomicrography with the Ciné Kodak. Trans. Soc. Mot. Pict. Engineers*, No. 30, p. 213; August, 1927.

quite accurately. It was found that by making the eyepiece quite high powered (making the images larger than the apparent screen size), the focus on the screen was made more critical even when the original visual image was so highly magnified as to be a bit fuzzy. Naturally, some subjects stand this over-enlargement better than others, so a series of eyepieces are in use.

The nature of the rest of the set-up was thus somewhat determined since the camera is used in its usual horizontal position with this beam splitter.

FIG. 1. *Set-up with Newman-Sinclair camera.*

A Universal camera has been used for most of the slow speed work because it was available and easy to adapt to a chronometer system for indicating the condensation of time on the screen. It is an extremely poor type for the purpose, violating most of the specifications advocated on page 4; in fact it was not until it was clamped tightly with angle irons on the side that all noticeable vibrational effects were eliminated. For camera speeds faster than those used for growth photography, a camera is used that is built lower and operates more easily.

CAMERA SUPPORT

Since we are considering a semi-portable set, a camera support with a concrete base obviously could not be used.

A cast iron tripod with a relatively wide spread of legs is used to insure stability. Since the microscope is supported near one edge of a table, the

front face and two legs of the tripod are almost vertical so that the camera can be set close to the microscope. The support is cast with as few joints as possible and has no hinges or swinging joints and the legs are tied with struts near the bottom. It can be leveled and the camera adjusted to the height of the microscope table by sliding members within the legs. These are commercial Shelby steel tubes that are moved by a 2 3/8 inch hexagonal nut and thread, then clamped in two places when in use. Once set, the height is not changed unless the camera or microscope support is changed. It is massive, weighing almost 500 pounds.

The head consists of two concentric cylinders of large diameter. The

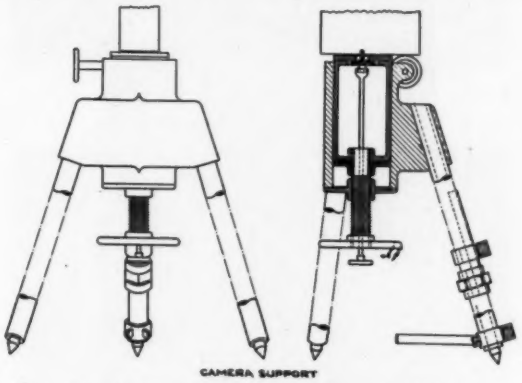


FIG. 2. *Double sketch of head of camera support.*

inner polished iron cylinder, about 6 1/2 inches in outside diameter, carries the camera plate and may be raised or lowered smoothly and precisely for a vertical distance of 4 7/8 inches by a jack screw from below. Usually, the apparatus is used with the tube quite low so that its diameter is greater than the height exposed from its jacket. It is clamped by the one-inch thick cast iron split ring that is part of the casting of the head. As on the arm of a milling machine, when it is firmly clamped by large thread and lever, the head becomes practically one unit.

Now, no surface supported by a central shaft is free from the influence of vibrations, even though it is also supported on its periphery. Therefore, after raising or lowering the camera *and* after clamping it in position, the central screw support is withdrawn. This slight withdrawal of the central screw shaft greatly reduces the susceptibility to vibration.

A key, backed by a spring, operates through the outer one-inch jacket and fits into a vertical slot in the surface of the inner sliding cyl-

inder. With the key in place the camera can be screwed upward and free of the light lock without noticeable tendency to rotate, but when the key is withdrawn, the camera with its split prism device can be swung aside and the microscope used for direct visual examination.

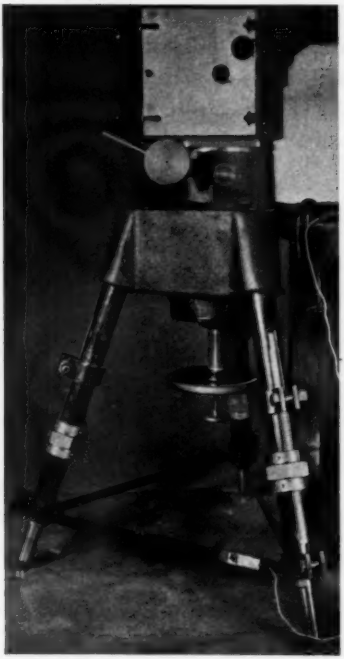


FIG. 3. *View of camera support.*

The camera can then be snapped back into its centered position above the microscope, easily and quickly. The key and slot are made slightly wedge-shaped to take up any play caused by use.

CAMERA DRIVE UNIT

A continuous motor drive for the camera was adopted rather than that of an intermittent mechanism,[1] both because of its greater simplicity and also because of the lower level of illumination that can be used. This was very advantageous in the photography of growing organisms.

A smoothly running set of gears such as would produce little vibra-

tion and would make available a large range of speeds is very expensive if a single unit is produced, even though standard gears be used. A pulley system with a standard 1:32 gear reduction unit and a few gears for

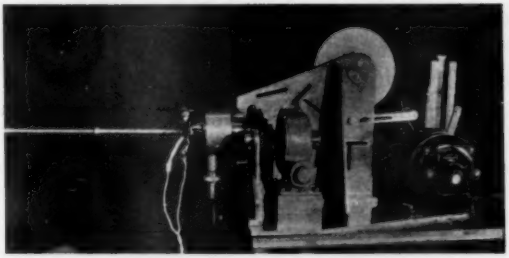


FIG. 4a.

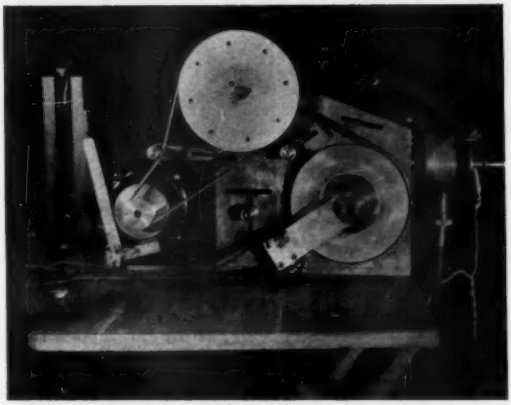


FIG. 4b. *Camera drive from both sides.*

the slowest speeds was devised and built by the Development Department of The Eastman Kodak Company for but a fraction of the cost of a complete gear unit. It has proved highly satisfactory. It has a driving speed variation from twice normal cranking speed, (two frames per second), to one frame every four minutes, at which speed two and one-half days of photography would be depicted in one minute on the screen, and it operates with any speed in between, that is, attainable by a factor of two. Seamless woven belts are used and it has been designed to have the least possible number of pulleys in the train. This has materi-

ally reduced vibrations. In order to reduce slippage, the pulleys are as large in diameter as was convenient and all of the belts have adjustable idlers. The motor is the General Electric Type BKS, 1/6 horse power 1725 rpm, mounted on rubber. The pulleys on the motor shaft must, therefore, be made correspondingly larger in diameter by a small amount than if the motor speed had been twice normal or 1920 rpm. All of the three pulleys on the motor shaft have the same diameter which can be called 1920/1725 of unity. Then those on the drive shaft, reading from

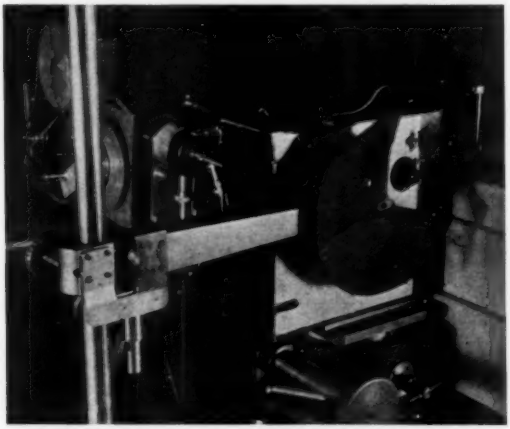


FIG. 5. *Time recording system.*

the outside, (lower right in Fig. 4b) could be called 1:2:4, and those on the idler (top of Fig. 4b) 4:1:1. A simple clutch of the tube and pin type disconnects the reduction gears when speeds greater than 60 rpm are used. The drive shaft head fastens into four outlets according to the range of speeds used. On the other side of the 1:32 gear reduction unit, a loose chain is used instead of a belt. An auxiliary drive shaft and head is used without the flexible cable attachment when the shutter is not needed. Thus, the shutter need never be put out of synchronism. A drive shaft with two universal joints is used. An ordinary Century Studio Stand on steel plates mounted on rubber sponges makes an almost ideal support for the motor drive, since it is sturdy and is easily and quickly adjustable in height.

Since we have been working with some organisms that are sensitive to light, a mercoid switch is mounted at the base of the drive shaft and

tilted by an eccentric in such a way as to turn off the microscope illumination whenever the camera shutter is closed. An auxiliary shaft without this switch is used for fast camera speeds.

INDICATION OF TIME CONDENSATION

One successful method of indicating the time condensation in pictures of growing organisms is to have a picture of a watch in one corner of the film. This method, unlike the use of titles, is independent of the speed of projection. We have imaged an ordinary watch through the back of the film, using the reflex finder with a Ciné Kodak anastigmat substituted for the usual eye lens. A permanent diaphragm of $f/8$ is fitted into the lens. Any markedly greater aperture seems to be unsatisfactory when operating through the back of the film. It was found necessary to replace the mirror with a prism, but if the mirror of the reflex is a single surface this might not be necessary.

An auxiliary shutter, synchronous with that of the camera is needed in such a system. The inertia of the shutter should be quite small and the shutter be counter-balanced to allow for its aperture. We have found a bristol board shutter, because of its light weight, to be as satisfactory as any other. In our case this is operated by a nine foot flexible shaft cable 5/16 inch in diameter, the combination "U" of the S. S. White Dental Company. Duplicate gears at each end of the shaft are used to speed it up five times, and thus increase its efficiency. The shaft is driven from a gear head which also drives the shaft for the camera (Fig. 4). This shaft must under no circumstances rest directly on the floor or touch the camera support. We have supported the loop on rubber sponges.

The thermostat inclosing the microscope for growth photography is easily removable, leaving the microscope still centered on the cast iron plate support. This plate can be leveled, since both the microscope and camera should be level, if the field on the film is to correspond to that marked in the eyepiece. Since leveling screws might admit vibrations, the plate is supported at three corners by inclined planes. Since each corner is forced down by a clamp or weight, the plate is easily leveled and firmly secured.

ON TEMPERATURE CRESTS IN CANDO-LUMINESCENCE*

By E. L. Nichols and H. L. Howes

[Department of Physics, Cornell University, Ithaca, N. Y. Received November 4, 1931]

Detection of the cando-luminescence of oxides, such as the rare earths, becomes more and more difficult as the temperature rises. Below the red heat all visible radiation is of the nature of luminescence; above the red heat whatever luminescence occurs is superimposed upon the radiation due to temperature and is more or less effectually submerged and disguised. Fortunately for the study of this type of radiation, there are sudden and sometimes very great accessions in cando-luminescence at certain definite temperatures and these give well marked maxima in the curves for the ratio of the brightness of the luminescent oxide to that of a black body at the same temperature. As has been pointed out in previous papers,[1] the temperatures at which these crests occur are characteristic of the activator and are to a great extent independent of the material in which the activator is in solid solution. This statement is confirmed and extended in our present experiments as will appear upon consideration of the curves in Figs. 3 to 10. In cando-luminescence, moreover, departures, from the temperature relations of ordinary incandescence are by no means confined to brightness alone. With change of temperature the emission color of a luminescent oxide frequently undergoes striking modifications. A substance the glow of which, when it is excited to luminescence at one temperature, is greenish, may exhibit a strongly ruddy hue at some higher temperature or vice versa. Thus gadolinium oxide under excitation by the hydrogen flame glows green below 200°C and red at 500° (Fig. 1). The cando-luminescence of neodymium oxide is predominantly greenish between 850° and 1000°, ruddy above 1150°. Praseodymium glows green between 800° and 1100°, red above 1150°, etc. etc.

The obvious explanation is that the spectrum of a cando-luminescent oxide is composite, and is essentially identical with the spectrum of the same substance when excited at ordinary temperatures in the cathode tube. Bands in one region of the spectrum are predominant at a certain temperature, those in another region at some other temperature, a

*The senior author wishes to make acknowledgement to the Heckscher Research Council of Cornell University for assistance rendered in support of this research.

[1] Nichols, Howes & Wilber: Carnegie Institution of Washington, Publ. 384, chapter X, p. 265 et seq.

change dependent upon profound modifications in the selective absorption of the glowing body with variations of temperature. For such a supposition we have a considerable experimental foundation in observations described in earlier papers, e.g. on the essential identity of cathodo- and cando-luminescence of beads,[2] on changes in the body

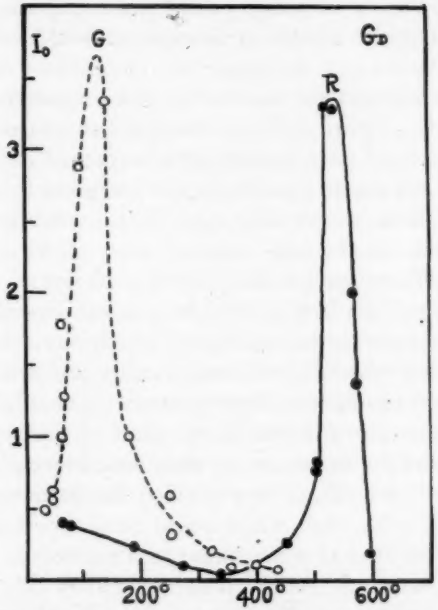


FIG. 1. *Temperature crests of Gd_2O_3 below 600° C. Brightness (I_0) is in cp./cm²×10^{-4}. Curve G viewed through green filter. Curve R; viewed through red filter.*

color of oxides with temperature,[3] on the relation of temperature crests and color changes of luminescence, and on temperature crests and structural changes of beads.[4]

For the detailed quantitative study of these effects, many examples of which have been noted in previous communications, and particularly for the accurate location of temperature crests, the following procedure, slightly modified from that of our earlier work, has been used in the investigation described in the present paper.

The oxide to be tested, which had been previously heated to strong

[2] Nichols and Howes: J.O.S.A. *13*, 586; 1926.
[3] Nichols: Phys. Rev. (2) *22*, 420; 1925.
[4] Nichols, Howes and Wilber: J.O.S.A. *14*, 205–222; 1927.

incandescence, was spread in a thin layer upon the end face of a cylindrical block of copper (5×3 cm). This layer, which was just thick enough to be opaque to radiation from the underlying surface of the block (thickness about 0.01 cm) was rendered as smooth and uniform as practicable by rolling under a dry rod of glass or glazed porcelain. The temperature of the copper surface, which earlier experiments had shown to be closely identical with that of the superimposed layer of oxide, when of the above-mentioned thickness, was determined by means of a thermo-electric element one junction of which was formed by the contact of a fine wire of pure platinum swedged into a narrow groove in the block and hammered until the flattened surface of the wire was flush with the surface of the copper. The copper block was heated from below with a Bunsen flame or ordinary blast lamp applied horizontally and the layer of oxide was brought into contact with the active zone of a small hydrogen flame applied obliquely from above.

The brightness of the luminescent surface was determined by means of an optical pyrometer the filament of which was calibrated to give degrees centigrade which in turn were readily convertible into candle power per square centimeter. Observations were made alternately with a red and a green color filter in the eye-piece of the pyrometer. These screens were mutually exclusive, i.e. when superimposed no measurable light was transmitted. Thus they divided the luminescence into two regions, red and green-blue, which could be observed separately. The red screen (screen *R*) had a maximum transmission at approximately .65μ; the green screen (screen *G*) at approximately .52μ. They had the further essential feature of affording a reasonable color match between the luminescence and the light from the filament.

Mounted on the copper block in the manner already described, gadolinium oxide was unresponsive to the hydrogen flame at 20°C. Below 40° however a "nile-green" luminescence appeared which was measurable through the green screen at 37° with a brightness of the order of .00005 cp/cm^2. Above this temperature the green component increased rapidly in brightness, reached a maximum above 100°, then fell rapidly and became imperceptible at about 450°. Indeed for a range of about one hundred degrees, circa 350° to 450°, luminescence to the naked eye seemed to be virtually extinct. With further rise of temperature a new glow appeared, ruddy in tone, which reached a maximum above 500°, and disappeared in the now rapidly increasing incandescence just above 600°. In Fig. 1, where curves *G* and *R* refer to the light transmitted by the "green" and "red" screens, respectively, the foregoing results are

depicted graphically. Brightness is in cp/cm^2×10^{-4}, temperature in degrees centigrade. The diagram serves to locate the two temperature crests definitely; the "green" crest at 130°C and the "red" crest at 540°C.

Observations with a hand spectroscope revealed two bright bands:

(1) at .540μ (corresponding to the "very strong" doublet found by Urbain[5] in the cathodo-luminescence of gadolinium sulphate at .5402μ and .5415μ)

(2) at .605μ (corresponding to Urbain's "very strong" band at .6052μ in samarium dissolved in CaO).

The shift from green to red is to be explained by the suppression of the gadolinium luminescence at higher temperatures due to the presence of a trace of samarium in solution; a phenomenon described in a subsequent paragraph of the present paper. Miss Frances G. Wick in a recent study of thermo-luminescence[6] discovered similar temperature crests in the glow of fluorites containing traces of rare earths. When these were heated to bring out their thermo-luminescence four sharply marked maxima of brightness occurred. As the substances in process of heating passed through these temperatures bright bands appeared and disappeared successively in the spectrum of the glow and these corresponded in location to the bands characteristic of the following rare earths as earlier observed by Urbain in his study of cathodoluminescence:

Crest	Temperature	Element	Band
1	77°C	Samarium	.5700μ
2	169°C	Dysprosium	.5800–.5900μ
3	211°C	Terbium	.5550μ
4	238°C	Terbium	.5380μ

Thus we find that solids containing rare earths as activators have narrow banded luminescence spectra characteristic of the activator and that the same bands appear whether excitation be by cathodo-bombardment, by heat (as in thermo-luminescence), or by the hydrogen flame.

CRESTS AT HIGHER TEMPERATURES

On passing from the lower range of temperatures covered by the foregoing experiments to the range of incandescence, both temperature and

[5] Urbain: Ann. d. chem. & physique; *28*, 340; 1909.

[6] Wick: Wiener Sitzungsberichte: *139*, 497; 1930; also J.O.S.A. *21*, 223; 1931.

brightness were determined by means of the pyrometer for which purpose we used the following method, developed from our earlier procedure in the study of incandescent oxides.[7] The outer face of the base of a thin alundum crucible (inverted), served as a mounting for the oxide under observation and for the black body used for comparison. The arrangement which was found to give the most accurate determination of temperature is shown in Fig. 2, in which the circular base of the crucible is divided into three regions two of which (B_1 and B_2) are coated with a thin layer of black uranium oxide, while the intervening strip (O) is filled with the substance to be studied. When the H-O flame, applied

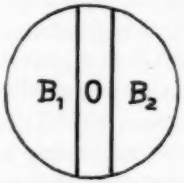


FIG. 2. *Oxides on crucible bottom. B_1B_2, uranium oxide; O, rare earth.*

obliquely from above for heating the preparation thus mounted and at the same time for exciting the oxide O to luminescence, is so adjusted that the surfaces B_1 B_2 contiguous to O on either side, are equally bright, it is assumed that the intervening strip of oxide is at the same temperature, provided its surface lies in the same plane; an assumption justified by many observations.

Under these conditions, any oxide of the class under consideration would glow more feebly than B_1B_2 if non-luminescent at the temperature of observation, but would have the hue characteristic of incandescence at that temperature, i.e. in general the hue of the contiguous B_1B_2. If, on the other hand, the oxide be luminescent under excitation by the flame, the strip O will in general be much brighter than B_1B_2 and may differ from B_1B_2 strikingly in color. In short the color-temperature and brightness-temperature relations of these oxides are much more complex than in the case of bodies which glow by incandescence alone.

Although the visible radiation of cando-luminescent substances containing the rare earths is highly selective, consisting of bright bands superimposed upon the incandescence spectrum and the complete separation of these two effects is difficult, to say the least, observations through the red and green screens, already described, afford useful in-

[7] Nichols; J.O.S.A. *13*, 661–677; 1926.

formation about the existence, intensity, and location of temperature crests, even where the luminescence bands are so completely merged in the incandescence as to be indistinguishable to the eye.

In carrying out the method outlined above the following procedure was adopted:

(1) The H-O flame was so regulated for the proportion of oxygen as to give the desired temperature.

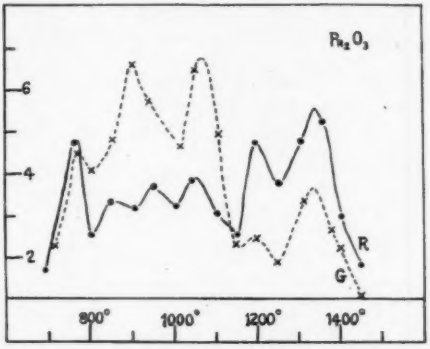


FIG. 3. *Temperature crests of praseodymium. Curve G; viewed through green filter; Curve R; viewed through red filter. Brightness* (I_o/I_{bb}) *is in terms of that of a black body at the same temperature.*

(2) The flame was so shifted in position as to give uniform excitation and also equality of brightness of B_1 and B_2, i.e. of the uranium oxide on both sides of the strip O.

(3) Pyrometer readings were made:

(a) of B_1.
(b) of strip O, viewed through "red" screen
(c) of B_2
(d) of B_2
(e) of strip O, viewed through "green" screen
(f) of B_1.

Readings were in milliamperes flowing through the pyrometer filament when of the same brightness as B_1B_2 or of the strip O respectively. These were converted into degrees centigrade by means of the calibration curve of the instrument and gave:—

$T_{B_1B_2}$ the actual temperature of B_1B_2 and of strip O also T_O the "color-temperature" of strip O corresponding to the temperature $T_{B_1B_2}$. The brightness $I_{B_1B_2}$ and I_O corresponding to $T_{B_1B_2}$ and T_O were expressed

in candle power per square centimeter. For convenient graphical representation, because of the enormous range of brightness between 600°C and 1500°C the ratio $I_O/I_{B_1B_2}$ was commonly used.

Measurements were made thus upon the oxides of praseodymium,

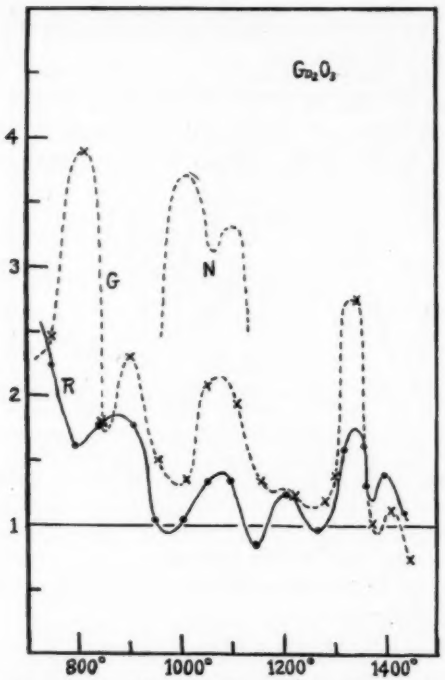


FIG. 4. *Temperature crests in gadolinium. Curve G; viewed through green filter; Curve R; viewed through red filter. Brightness* (I_0/I_{bb}) *is in terms of that of a black body at the same temperature.*

gadolinium, neodymium, dysprosium, and samarium, and also upon the following combinations:

praseodymium oxide +1% gadolinium oxide
gadolinium oxide +1% praseodymium oxide
praseodymium oxide +1% samarium oxide
gadolinium oxide +1% samarium oxide
gadolinium oxide +1% neodymium oxide
neodymium oxide +1% gadolinium oxide

By 1% is meant that in the preparation of the mixture the amounts

used were such as to give approximately 100 parts of the solvent to one part of the dissolved oxide after ignition.

In the following tables and discussions the chemical symbol of the element is commonly used, for brevity, to denote whatever oxide (or possibly group of oxides) may result from the heat treatment of the sample.

TABLE 1. *List of temperature crests.*

	Pr	Gd	Nd	Dy	Sa
"Green" screen	770°				
		810°	880°	850°	810°
	905°	900°	925°	955°	920°
	1070°	1075°	1020°		1020°
			1105°	1105°	1125°
	1205°	1205°	1270°		1235°
	1330°	1330°		1305°	1350°
		1410°	1410°	1465°	1470°
"Red" screen	770°		790°		
	850°	875°		850°	
	950°		905°	955°	925°
	1055°	1080°	1055°		1025°
			1160°	1135°	1130°
	1205°	1205°	1270°	1265°	1235°
	1335°	1335°		1350°	1350°
		1405°	1415°	1465°	1470°

From the numerous sets of observations made in the course of our work, the following conclusions were drawn:

(1) Given identical preparation and heat treatment, for an oxide or for combinations of oxides (of the "rare earth" group) the location of temperature crests is *definite and reproducible.*

(2) The brightness of luminescence is not as a rule strictly reproducible, since this depends in part upon the activity of the exciting flame which is not wholly under control by existing methods. For this reason data concerning brightness have not been tabulated but are represented by curves which illustrate the effects observed in individual but quite typical cases. (See Figs. 3, 4, 5, 6, 7 etc.)

(3) Modifications in the preparatory heat treatment, e.g. a lowering of the temperature at which ignition before excitation occurs, may profoundly affect the brightness curve and the location of temperature crests. Thus, measurements of the cando-luminescence of gadolinium oxide sometimes bring out a double peak at 1015° and 1100° in place of

the usual crest at 1075°. (See curve *N* in Fig. 4). Since Nd has crests at 1015° and 1105°, as may be seen by reference to Table 1 and to Fig. 5, and since Nd in solution in Gd tends to suppress the Gd crests, as will be shown in a later section of this paper, (see Dominance and Suppression) it seems reasonable to assign the outcropping of such crests to the presence of a trace of Nd in our sample of Gd.

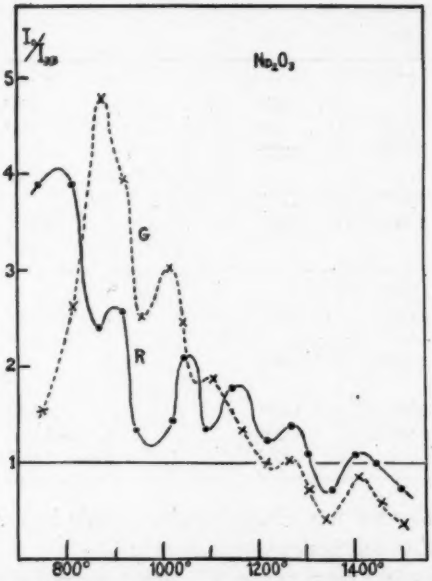


FIG. 5. *Temperature crests of neodymium. Curve G; viewed through green filter; Curve R; viewed through red filter. Brightness* (I_o/I_{bb}) *is in terms of that of a black body at the same temperature.*

(4) The brightness of an incandescent rare earth, in spite of the presence of activators (other rare earths) for which it serves as solvent, is not always greater than that of a black body. Thus the brightness curve for dysprosium (Fig. 6) lies below unity for all temperatures above 875°. It exhibits the almost rhythmical set of temperature crests characteristic of this class of oxides, but these might be explained as due to successive changes in absorbing power, accompanied by corresponding fluctuations in ordinary incandescence. In all the other oxides investigated, however (see Figs. 3, 4, 5) brightness exceeds unity throughout most of the temperature range explored.

Table 1 gives a list of temperature crests located by observations of Pr, Gd, Nd, Dy, and Sa with the "green" screen and "red" screen respectively. Crests agreeing within five degrees are regarded as identical within the errors of location, those differing by ten degrees as possibly identical.

A comparison of the observations taken through the two screens shows wide dissimilarities. Out of a total of 57 crests listed, only 16 are

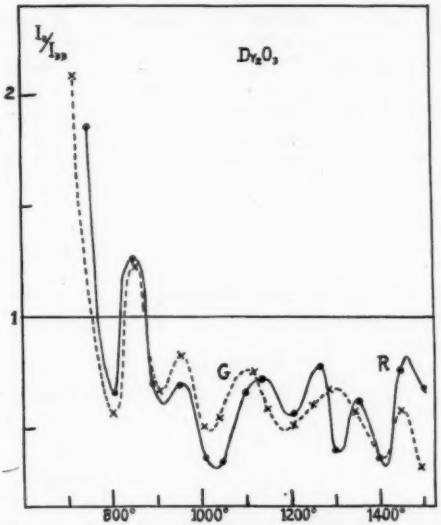


FIG. 6. *Temperature crests of dysprosium. Curve G; viewed through green filter; Curve R; viewed through red filter. Brightness* (I_0/I_{bb}) *is in terms of that of a black body at the same temperature.*

common to both regions of the spectrum. In other words the luminescent activity which gives rise to temperature crests usually has its seat in a group of bands either in the red of the spectrum or in the green and is therefore not generally observable through both screens.

Table 2 shows the number of crests common to more than one element arranged for convenient comparison: also the non-coincident crests.

Inspection of these two tables, at first sight seems to indicate merely that we have to do with substances containing a variety of unknown activators (a condition to be anticipated from the chemistry of the rare earths), the identification of which from these data is hardly possible.

Certain characteristics however appear to be of significance. For example:

(1) Where discrepancies occur between crests in the red and green, the missing places as a rule are taken by crests coincident with crests in other substances: Thus of twenty five such replacements in Table 1, nineteen are in coincidence.

TABLE 2. *Coincident and non-coincident crests.*

	Pr and	Gd and	Nd and	Dy and	Sa and
Number of coincidences between	Gd 4	Pr 4	Pr 1 Pr–Gd 1	Pr 2	Pr 0
	Nd 2	Nd 2	Gd 2	Gd 0	Gd 1
	Dy 2	Dy 0	Dy 2	Nd 2	Nd 2
	Sa 0	Sa 1	Sa 2	Sa 3	Dy 3
Non-coincident crests	Pr 1	Gd 0	Nd 2	Dy 2	Sa 1

(2) Coincidences tend to be adjacent. Thus there are adjacent crests in coincidence as below:

4 adjacent crests of Gd–Pr–Gd
2 " " " Pr–Dy
2 " " " Pr–Nd
2 " " " Nd–Sa
2 " " " Dy–Sa

or 12, as against 6 isolated cases of coincidence.

(3) Of the 41 crests under consideration, 6 occur in one substance only; 16 occur in two substances; 1 occurs in three substances. Thus there are only 23 independent crest locations in all.

DOMINANCE AND SUPPRESSION

Solid solutions of four of the rare earths at our disposal, in which each oxide was used as solvent and activator alternately, namely,

one part Gd dissolved in one hundred parts Pr;
" " Pr " " " " " Gd;
" " Gd " " " " " Sa;
" " Sa " " " " " Gd;
" " Sa " " " " " Pr;
" " Gd " " " " " Nd;
" " Nd " " " " " Gd

gave the results shown in Tables 3, 4, 5, and 6. The preparation and mode of observation were as nearly identical as possible with those used in the studies already described of the separate oxides. For ease of comparison, columns 1, 2 and 4, 5 in each table contain the crests assigned to the two components in Table 1. The study of dysprosium as solvent and activator was omitted for lack of sufficient material, and Sa in combination with Pr was used as activator only.

TABLE 3. *Gd and Nd.*

Location of crests (green)				Location of crests (red)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gd	Nd	Nd +1% Gd	Gd +1% Nd	Gd	Nd	Nd +1% Gd	Gd +1% Nd
					790°	790° Nd	790° Nd
810°				875°			
also *Sa*	880°	880° Nd					
900°		900° Pr					
also *Pr*	925°		925° Nd		905°	905° Nd	900° Nd
1075°		1070° Gd		1080°			
also *Pr*	1020°				1055°	1055° Nd	1055° Nd
	1105°		1105° Nd		1160°		1160° Nd
1205°		1205° Pr		1205°			
also *Pr*	1270°		1270° Nd		1270°	1270° Nd	1270° Nd
1330°				1335°			
also *Pr*							
1410°		1410° Gd		1405°			
also *Nd*	1410°				1415°	1415° Nd	1410° Nd

The most striking effect, which confirms certain observations on cathodo-luminescence already published,[8] may be briefly designated by the terms *Dominance* and *Suppression*. In Table 3 are recorded the temperature crests found when 1% of Gd was added to Nd (columns 3 and 7) and when 1% of Nd is added to Gd (columns 4 and 8). Where Nd is the activator (i.e. in solution) Nd crests only appear; all others disappear. Nd is *dominant*, Gd is *suppressed*. Where Gd is the activator, Nd is still dominant in the red but not in the green.

Now of the crests allotted to Gd in column 1, all six are found in the list of other oxides as may be seen by reference to Table 1. These coincidences are indicated in column 1 of Table 3, and their presence or

[8] Nichols, Howes & Wilber: *Cathodo-luminescence and the luminescence of incandescent solids*. Carnegie Inst. of Washington, Publ. 384, 1928.
Also, Nichols and Howes: Phys. Rev. (2) *12*, 351; 1908.

TABLE 4. *Pr and Gd.*

Location of crests (green)				Location of crests (red)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Pr	Gd	Pr +1% Gd	Gd +1% Pr	Pr	Gd	Pr +1% Gd	Gd +1% Pr
770°				770°			
				850°			850° Pr
	810°	815° Sa			875°		
905°				950°			
		950° Dy				950° Dy	
	900°		900° to 1000°				
1070°				1055°			1050° Pr
		1025° Sa					
	1075°	1075° Gd			1080°		
						1110° (?)	
			1150° Nd				1135° Sa
1205°			1200° Pr	1205°			
	1205°				1205°		
		1230° Sa					
1330°			1300° (?)	1335°		1340° Pr	1335° Pr
	1330°				1335°		
	1410°	1410° Gd			1405°		
1550°				1555°			

TABLE 5. *Gd and Sa.*

Location of crests (green)				Location of crests (red)			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Gd	Sa	Sa +1% Gd	Gd +1% Sa	Gd	Sa	Sa +1% Gd	Gd +1% Sa
810°			815° Gd or Sa	875°		885° Gd	
	810°						
900°		905° Pr					
	920°		920° Sa		925°		925° Sa
1075°		1070° Gd	1070° Gd	1080°		1085° Gd	1090°
	1020°				1030°		
						1150° Nd	
	1125°				1130°		
1205°				1205°		1210° Pr	1220°
	1235°	1240° Sa	1235° Sa		1235°		
1325°				1335°		1335° Gd	1330° Gd
	1350°		1350° Sa		1350°		
1410°		1415° Gd	1415° Gd	1400°		1400° Gd	1405° Gd
					1470°		

absence where Gd is added as an activator affords a plausible criterion as to the oxide to which they should be assigned. Thus the absence of the crest at 810° in Nd+1% Gd, column 3, Table 3 may mean that it belongs to Sa and not to Gd; likewise the absence of crests at 900°, 1205°, and 1330° in Pr+1% Gd, column 3, Table 4 may indicate that they belong to Pr and not to Gd, while the crests at 1075° and 1410° which appear in column 3 of both tables belong to Gd. The crests in column 3 of both tables are provisionally assigned in conformity with this criterion.

There are obviously marked differences in the potency of the four activators in causing suppression. In the other three cases where Gd is in solution it is usually dominant but not always completely so. Thus it completely suppresses Sa in the red (Table 5, 7) and Pr in the green (Table 4, 3), permits the appearance of one band of Sa in the green (Table 5, 3), of Pr in the red (Table 4, 7) and of Nd in the green (Table 3, 3). In the red it is completely suppressed by Nd (Table 3, 7) as mentioned above. Similarly Pr in solution completely suppresses Gd in the red and green (Table 4). Unfortunately we have no record of its performance as an activator with Nd or Sa.

Sa in solution is a very indifferent activator. In Pr it is partly suppressed in the red, or possibly completely so since two crests assigned to it (1350° and 1470°, Table 6, 6) also occur in Dy and may belong to that substance. In the green (Table 6, 3) only one crest of Sa appears. When dissolved in Gd, Sa is represented in the red by a single crest (Table 5, 8). In the green four crests of Sa are present, but Gd is not suppressed.

Among the temperature crests located when an activator is added to one of the rare earths here under consideration, i.e. Pr, Gd, Nd or Sa, crests belonging to neither solvent nor activator sometimes appear. Thus in Table 3 there are two crefts of Pr, four crests of Sa, one of Dy, and three or possibly four of unknown origin; in Table 5 two of Pr and one or two of unknown origin; in Table 6, one of Gd and possibly three of Dy.

The occurrence of four Sa crests in Talbe 4, where the only known activator is Gd, is quite in line with our earlier studies of rare earth activators in cathodo-luminescence.[9] When in the course of that investigation a trace of neodymium oxide was introduced into CaO, the the luminescence spectrum invariably obtained "*was that of samarium.*" We have here a definite link between *cathodo-luminescence* and *cando-luminescence.*

[9] Nichols, Howes, & Wilber, lc.

ENHANCEMENT BY KNOWN ACTIVATORS

In the foregoing measurements of single rare earths the results of which are depicted in Figs. 3 to 7, excess of brightness above that due to temperature must, strictly speaking, be ascribed to unknown activators. When however a known rare earth such as Gd, Nd, or Sa is added in definite proportion the brightness of the glowing mixture at various temperatures as compared with that of the components under like conditions is of interest. This ratio was directly measured by comparing the brightness of the activated and the unactivated oxide under identical

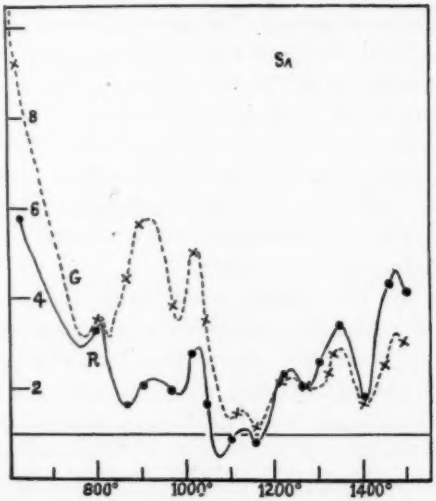


FIG. 7. *Temperature crests of samarium. Curve G; viewed through green filter; Curve R; viewed through red filter. Brightness* (I_a/I_{bb}) *is in terms of that of a black body at the same temperature.*

conditions as to temperature and excitation. To this end the method described in an earlier paragraph was slightly changed. Upon the central strip O (Fig. 2) the activated and unactivated oxides were mounted side by side and were compared with the contiguous surfaces B_1 and B_2 throughout the usual temperature range from 700° to 1500°. The ratio I_a/I_0 or brightness of activated oxide to brightness of unactivated oxide was taken as expressing the enhancement.

Such an experiment obviously may take two forms. We may compare the brightness of the combination either with that of the solvent alone, or with that of the activator alone (i.e. in the absence of the solvent.)

TABLE 6. *Pr and Sa.*

Location of crests (green)			Location of crests (red)		
(1)	(2)	(3)	(4)	(5)	(6)
Pr	Sa	Pr +1% Sa 700°	Pr	Sa	Pr +1% Sa
770°			770°		
			850°		850° Pr
	810°				
905°		900° Pr	950°		945° Pr
	920°			925°	or Gy
1070°		1080° Gd	1055°		1050° Pr
	1020°			1020°	
	1125°			1130°	
1205°		1215° Pr	1205°		1200° Pr
	1235°			1235°	
1335°			1335°		
	1350°	1360° Sa		1350°	1350° Sa or *Dy*
				1470°	1450° Sa or Dy
1550°			1555°		

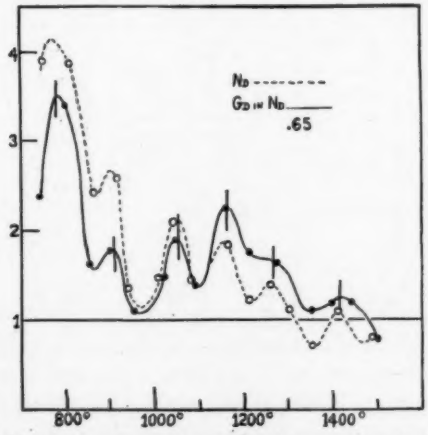


FIG. 8. *Temperature crests of neodymium and of gadolinium in neodymium compared (red screen).*

The effect of adding one rare earth to another in proportions supposed to be conducive to activation is not always to increase the lu-

minescence. For example, when 1% Gd is added to Nd the temperature crests in the red, as has already been shown (Table 3, 8), are those of Nd. Below 1100°, as appears in Fig. 8, the brightness of the unactivated everywhere exceeds that of the "activated" oxide. Above that temperature there is everywhere a slight enhancement: i.e. I_a/I_0 is greater than unity. In the green of the spectrum where, as indicated in Table 3, 4, all crests of Nd are suppressed excepting that at 880°, enhancement by Gd is insignificant above 950°. In the neighborhood of the 880° crest the ratio I_a/I_0 rises to the value of 1.4 and there are indications that at some lower temperature, 750° or less, enhancement may exceed 3.0. When, per contra, 1% Nd is added to Gd, not only is there a complete suppression of the crests of Gd throughout the green and red, as is recorded in Table 3, 4 and 8, but a *marked reduction in brightness*. At the temperatures corresponding to the crests of Gd, for example, where the luminescence is greatest the values of I_a/I_0 are all less than unity (see Table 7.) Under the conditions of our experiment Nd dissolved in Gd can scarcely be deemed an activator.

TABLE 7. *Reduction in the luminescence of gadolinium oxide produced by 1% of neodymium oxide.*

Red				Green			
Temp. of crest	I_a/I_0	Temp. of crest	I_a/I_0	Temp. of crest	I_a/I_0	Temp. of crest	I_a/I_0
875°	0.11	1335°	0.97	810°	0.12	1205°	0.66
1080°	0.68	1405°	0.20	905°	0.41	1335°	0.80
1205°	0.63			1075°	0.55	1405°	0.25

In strong contrast with these results are those obtained when 1% of Sa added to Pr (I_a) is compared with Sa alone (I_0), as depicted in Fig. 9 where ordinates are values of the ratio I_a/I_0 and abscissas are temperatures. The curve for the red end of the spectrum indicates that the enhancement is by no means the same throughout the range covered by the measurements but is greatest at certain definite temperatures which correspond in general to the dominant temperature crests of the combination (see Table 6, 4, 5, 6). Thus four adjacent crests, at 850°, 950°, 1055° and 1205° coincide with the crests of Pr, the locations of

which are shown by short vertical lines. The very prominent crest at 1360° is probably assignable to Sa rather than to Pr or Dy, since it recurs in the green curve also and similarly the minor crest at 1450° to Dy rather than to Sa for the same reason. The curve for the green above 1200° is a replica of the "red" curve. Below that temperature we note

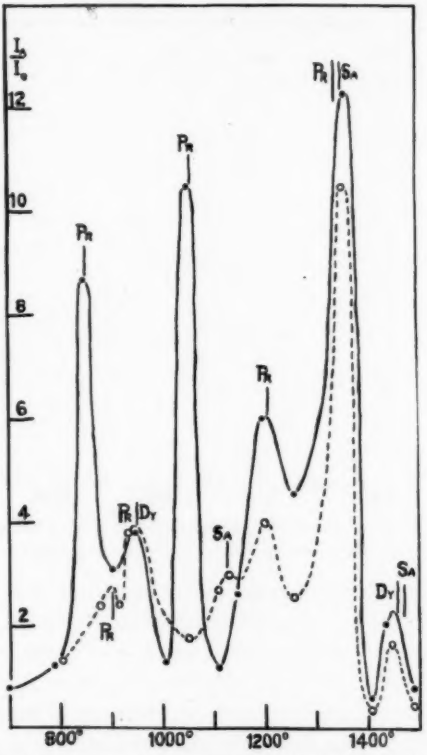


FIG. 9. *Enhancement of praseodymium by samarium (red filter). Ordinates are ratios of the brightness of the activated oxide to that of the unactivated oxide.*

the appearance of minor crests corresponding to the temperature crest of Sa at 1125° and of Pr at 905°. The complete disappearance in the green of enhancement at 850° and 1055°, so prominent in the red, accords with the absence in the green of crests of Pr. The enhancement at 950°, which occurs in both red and green, may be due to Dy which has crests in both at that temperature.

SUMMARY

(1) Further evidence is afforded in this paper of the existence of numerous definite maxima in the brightness-temperature curves of rare earths rendered luminescent by the hydrogen flame.

(2) These temperature crests are characteristic of the activator and serve to identify it.

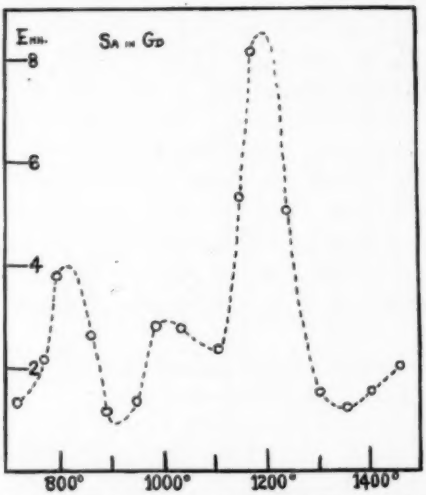


FIG. 10. *Enhancement of gadolinium by samarium (green filter). Ordinates are ratios of the brightness of the activated oxide to that of the unactivated oxide.*

(3) When the rare earths are heated to incandescence in the hydrogen flame their brightness, in general, exceeds that of a black body of like temperature. At the crests the luminescence is frequently many times as bright as the corresponding incandescence of a black body: at the lower stages of incandescence it may be enormously brighter.

(4) When a trace of an activator, such as Gd, Nd, or Sa, is dissolved in one of the rare earths under consideration, several effects are noted:

(a) Certain crests are suppressed
(b) Other crests persist
(c) New crests may appear, assignable to activators not otherwise known to be present
(d) There is marked enhancement of the luminescence at the temperatures of the persisting crests whatever their source.

(5) These experiments afford new evidence in favor of the view, expressed in our earlier investigations, that luminescence occurs chiefly at certain temperatures of transformation at which the substance under-

goes a structural rearrangement during which it is especially susceptible to excitation. The temperature crests here described indicate, for the rare earths, the location of these temperatures of transformation.

L'Atome de Bohr. La Mechanique Analytique et les Quanta, Les Spectres de Multiplets. By Leon Brillouin. Pp. 363, Leo Presses Universitairesde Paris, France. 1931. 100 Fr.

The simplicity and physical tractableness of the older quantum mechanics will doubtless keep it of fundamental importance for sometime to come. With the hypothesis of the spinning electron and Pauli's principle, it furnishes a very suggestive picture, and led to many results which were easily justified by the newer formulations of atomic theory.

In this new volume there is presented an elegant and complete development from a modern viewpoint. The first third is devoted to the necessary analytical mechanics, including a chapter on the relation between geometrical optics and classical dynamics. General formulations on electromagnetism and relativistic mechanics follow. The principle results on the structure of the atom and the origin of spectra are then given. The problem of multiplets is treated clearly and in great detail. Chapters on the spinning electron, x-ray spectra and Pauli's principle follow. Coupling problems are discussed and the book is concluded with a discussion of spectral intensities. Full references to original literature are given throughout.

This book contains the lectures delivered by the author at Wisconsin in 1928 and later at the Sorbonne. As an account of the older quantum mechanics and "vector theory of the atom" it is unexcelled.

W. O. SMITH